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CTPB BACK-UP PROPELLANT FOR SAM-D

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Thiokol Corporation

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CTPB BACK-UP PROPELLANT FOR SAM-D

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The objective of this program was to tailor a propellant using the CTPB binder system to meet SAM-D requirements, which would serve as a back-up to the present HTPB binder system propellant selected for Engineering Development. This CTPB propellant was formulated for optimum aging stability at 130°F while maintaining adequate physical

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) properties to meet -30°F structural requirements. The initial SAM-D propellant was a CTPB formulation (TP-H7038) which showed unacceptable softening during aging at 30°F. It contained a trimodal blend (including special coarse) of AP oxidizer, and was formulated at a P/CA ratio of 1/.83 and a curing agent I/E ratio of 5.1. Numerous CTPB propellants having the same ingredients but formulated at P/CA ratios nearer 1/1 have better high temperature aging stability. Therefore, the primary approach investigated for improving aging stability was to increase the P/CA ratio to 1/1, lower the curing agent I/E ratio to 3.8/1, and use 2% TP-90B plasticizer in place of 1% DOA. After aging, this formulation (TP-H7070) showed no improvement in high temperature aging stability. The approach was modified to delete the special coarse AP (whose internal moisture was the probable source of aging degradation) from the TP-H7038 formulation. Substitution of additional unground AP for the special coarse AP, and adjustment of the aluminum particle size allowed the desired burning rate to be achieved. Initial propellant tensile properties were better than both TP-H7038 baseline and TP-H7070 propellant properties. Aging properties were significantly improved after 130°F storage. Use of a small amount of desiccant (similar to the 200 g. Molecular Sieves used in the present SAM-D motor) was shown to be required. With the improvements shown, the modified TP-H7038 formulation without special coarse oxidizer would be the better choice from the CTPB propellants for the SAM-D motor if, for some highly unlikely reason, it became necessary to substitute a CTPB propellant for the present HTPB propellant.

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A

SUMMARY

A back-up propellant based on the carboxyl-terminated polybutadiene (CTPB) binder system was tailored to meet SAM-D requirements. This propellant was formulated for optimum aging stability at +130°F while maintaining adequate physical properties to meet -30°F structural requirements. This propellant will serve as a back-up to the primary hydroxyl-terminated polybutadiene (HTPB) binder system propellant selected for the SAM-D Motor Engineering Development Program.

SAM-D motor development was initiated with a CTPB propellant, TP-H7038, which was formulated to meet strain requirements at -65°F and burning rate requirements dictated by grain geometry and motor performance parameters. The resulting propellant contained a trimodal blend of special coarse, unground and ground ammonium perchlorate (AP) oxidizer; a polymer/curing agent (P/CA) ratio of 1/.83; and a curing agent imine/epoxide (I/E) ratio of 5/1. Subsequent studies with this propellant showed unacceptable softening during aging at 130°F, necessitating a propellant change. The decision was made to utilize the HTPB system as the primary propellant for SAM-D, but to reformulate the CTPB propellant to act as a back-up.

Since other similar CTPB propellants with P/CA ratios nearer 1/1 had exhibited better high temperature aging stability, the primary approach to reformulating TP-H7038 was to increase the P/CA ratio while lowering the I/E ratio. This also required an increase in plasticizer content to maintain the desired crosslink density, and a possible change in plasticizers from DOA to TP-90B. Tests on propellant from subscale mixes made to evaluate these changes resulted in the selection of a formulation which was given the designation TP-H7070. The selected formulation met the tensile and ballistic property requirements of the program. It contained 2% TP-90B as the plasticizer, a P/CA ratio of 1/1, an I/E ratio of 3.8/1, but was otherwise identical to the standard TP-H7038 propellant in respect to solids. The ratio of AP particles used was the same: 45% special coarse (~400 microns)/27.5% unground (~200 microns)/27.5% ground (~17 microns).

This propellant was scaled up to the 420-gallon mixer to provide samples for characterization and aging tests. Ballistic properties characterization showed acceptable burning rate parameters. Bond properties as determined by composite adhesion samples were acceptable, but peel bond values were lower than expected and additional work in this area would be required before the system could be used in a motor. A complete physical property characterization was conducted to provide data for predictive structural analysis of the motor over its operating temperature range. Included were input parameters for a stress analysis as well as a definition of the failure characteristics of the propellant in terms of design allowable stress and strain conditions. All values obtained were within the expected range and typical for a highly-loaded composite CTPB propellant.

The TP-H7070 propellant aging program had the capability of extending to five years for some phases, but was discontinued after one year. Low temperature specimen storage showed no significant change in strain capability during six months at -30°F; however, at -50°F a minor to moderate reduction in elongation occurred. Bulk sealed storage for one year at ambient showed an expected minor post cure involving increased tensile strength, decreased elongation, and decreased strain endurance. The major change occurred at 130°F where a considerable decrease in tensile strength was experienced when aged in bulk sealed form. At the end of twelve months, the reduction in maximum stress was greater than 50% at the higher test temperatures. The softening experienced is comparable to that obtained with TP-H7038 under the same conditions, but was unexpected with the TP-H7070 propellant. Internal moisture was considered to be the most likely cause of the poor thermal stability, with the special coarse AP being the most probable source. An attempt was made to improve the propellant high temperature stability by desiccating samples with one surface exposed. The amount of desiccant used (1 to 2 grams) was based on the recommended 200g for the SAM-D motor. The results showed that the small amount of desiccant used did not improve the thermal stability of the TP-H7070 propellant.

A second approach was then attempted to reformulate the basic TP-H7038 propellant to improve high temperature aging stability. It was theorized that the propellant internal moisture content could be significantly decreased if 200 micron (unground) AP was substituted for the 420 micron (special coarse) AP fraction. Heretofore this approach was considered to be unacceptable since the burning rate could not be tailored sufficiently low to meet SAM-D requirements while maintaining a processable propellant with adequate physical properties. Recent studies with related propellants had shown that it was possible to replace the special coarse with unground AP and maintain physical and ballistic properties. A change from a nominal 16 micron to 30 micron aluminum particle size would also aid in obtaining the desired properties.

Two 4 1/2-gallon mixes of the modified TP-H7038 propellant were made with a 80/20 ratio of unground/ground AP, 30 micron aluminum, an I/E ratio of 5/1, and P/CA ratios of 1/0.80 and 1/0.83, respectively. The results indicated that the bimodal AP version of TP-H7038 could be reasonably processed, provide adequate tensile properties, and yield target burning rate (rate actually obtained slightly low). The mix with a P/CA ratio of 1/0.80 was scaled up to the 50-gallon vertical mixer (size limited by available funds) to provide samples for further ballistic and tensile properties evaluation and for a short aging program. Processing of this mix, W-24, was quite satisfactory.

A burning rate approximately 5 percent below target was obtained on Mix W-24. This result was very acceptable since it assured a wider range of burning rate tailoring ability while still achieving good physical properties and processing. Tensile properties obtained were considered to be quite good, and considerably better than those on TP-H7070 propellant.

Sufficient samples for a minimal one-year aging program were obtained, but available time allowed for only six months of testing. During six months at ambient, the bulk sealed and gradient samples showed an expected slight reduction in strain with no significant change in stress. Also, the bulk gradient samples experienced no surface-interior physical property gradients and no detrimental changes due to desiccation. However, gradient storage under nitrogen at 130°F without desiccant resulted in a surface-interior gradient with decreased tensile strength on and near the exposed surface. In the presence of desiccant, no surface-interior physical property gradient was apparent, but an expected minor reduction in tensile strength of the interior propellant was shown. This was also true for the bulk sealed propellant samples stored at 130°F.

Removal of the special coarse ammonium perchlorate oxidizer from the TP-H7038 propellant formulation has resulted in an improvement in the physical properties and in the high temperature (130°F) storage stability.

This was shown by comparison of the modified TP-H7038 formulation to the original TP-H7038 formulation and the TP-H7070 formulation also developed under this program. This comparison showed that the bulk sealed sample physical properties, and the depth to which surface-interior properties were affected in bulk gradient samples stored under nitrogen were altered to a much lesser degree for the modified TP-H7038 propellant. This indicates that the probable cause of the premature tensile property degradation at high temperature in the original TP-H7038 and TP-H7070 propellants is moisture, and specifically the high moisture content of the special coarse oxidizer. With the improvements shown, the modified TP-H7038 formulation without special coarse oxidizer can be substituted for the present HTPB propellant if it becomes necessary, for any unlikely reason, in the future.

FOREWORD

This program was conducted by Thiokol Corporation for the Propulsion Directorate, US Army Missile Research, Development and Engineering Laboratory, US Army Missile Command, Redstone Arsenal, Alabama 35809.

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Mr. E. R. Flemig served as Project Director, Mr. C. D. Wallace, Jr. as Program Manager, and Messrs. P. O. Blackwell and R. T. Davis as Principal Investigators. Mr. J. H. Bullington assisted in the program, and he and Mr. Wallace in the preparation of this report.

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FINAL REPORT

CTPB BACK-UP PROPELLANT FOR SAM-D

INTRODUCTION

The initial SAM-D motor development was initiated with a CTPB propellant (TP-H7038) which was formulated to meet strain requirements at -65°F. Additional studies with this propellant showed that it softened during aging at +130°F which necessitated a propellant change in order to meet storage requirements. Low temperature storage requirements for the motor were relaxed to -30°F, giving the option of reformulating the CTPB propellant to meet the high temperature (+130°F) storage requirement while maintaining adequate strain capacity at -30°F. A decision was made to utilize the newly developed hydroxyl-terminated polybutadiene (HTPB) system as the primary propellant for the SAM-D motor to obtain the desired storage and low temperature properties. Since the HTPB propellants were relatively new and were not proven in large scale motor programs it was desirable to have a back-up propellant that could be used in the event the HTPB propellant did not prove satisfactory for use in the SAM-D motor. The propellant selected as the back-up was the original CTPB propellant (TP-H7038) reformulated to meet the +130°F storage requirement. This study was devoted to developing and characterizing the new formulation to the point where it is ready for large-scale demonstration.

OBJECTIVE

The objective of this program was to tailor a propellant to meet SAM-D requirements using a binder system based on carboxyl-terminated polybutadiene (CTPB). The propellant was formulated for optimum aging stability at +130°F while maintaining adequate properties to meet SAM-D requirements at -30°F. The resulting propellant will serve as a back-up to the primary HTPB propellant for the SAM-D Motor Engineering Development Program.

TECHNICAL APPROACH

Numerous CTPB (HC) propellants having the same binder ingredients as the initial SAM-D propellant (TP-H7038) but formulated at polymer/curing agent ratios near 1/1 have much better high temperature aging stability. Based on these data, the primary approach proposed and selected for improving the high temperature aging stability of TP-H7038 propellant was to increase the polymer/curing agent (P/CA) ratio at lower curing agent imine/epoxide (I/E) ratios. This change in formulation would also require a higher concentration of plasticizer to maintain the desired crosslink density. After aging, the formulation developed with this primary approach showed no improvement in high temperature aging stability. Therefore, the approach was modified to delete the special coarse ammonium perchlorate (AP) oxidizer (whose internal moisture was the probable source of degradation during high temperature aging) from the TP-H7038 formulation. Heretofore, this latter approach was unacceptable since the burning rate could not be tailored sufficiently low to meet SAM-D motor requirements. However, recent studies with related propellants indicated that it was now possible to replace the special coarse material with unground oxidizer and maintain tensile and ballistic properties. Comparison of the aging results from the primary and alternate approaches should indicate whether the P/CA and I/E ratios or the internal moisture in the coarse AP was the cause of previous poor high temperature aging stability.

DISCUSSION

The program was divided into four phases of study as discussed below. The first three phases were concerned with the primary technical approach as originally proposed. The fourth phase, which was added after completion of the first three, was to investigate the alternate technical approach.

I. Tensile and Processing Properties - This phase consisted of the evaluation of various plasticizers and concentrations as well as variations in polymer/curing agent ratios.

II. Ballistic Properties - The formulation selected from Phase I studies was evaluated in ballistic test motors to determine effects of formulation changes on ballistic properties and make the required adjustment to meet SAM-D requirement.

III. Scale-Up, Characterization, and Aging - The propellant resulting from Phases I and II was scaled up to the 420-gallon mixer to demonstrate the practicality of producing and handling the selected composition on a large scale and to provide propellant for tensile and ballistic characterization and aging tests.

IV. Reformulation, Scale-Up, and Aging - The formulation developed and tested under Phases I through III exhibited equally poor high temperature aging stability as the initial TP-H7038 propellant. These data indicate that the probable cause of the premature degradation is moisture, and specifically the high internal moisture content of the special coarse oxidizer. TP-H7038 was reformulated to delete the special coarse oxidizer, evaluated in 4 1/2-gallon mixes to obtain processing, tensile, and ballistic properties, and scaled-up to the 50-gallon mixer to obtain propellant for tensile and ballistic properties and for aging tests.

A detailed description of the tests performed during each phase of the study is presented below:

Phase I - Tensile and Processing Properties

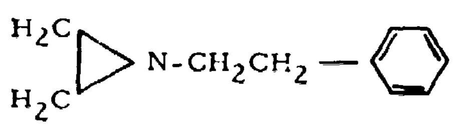
This phase of the study was devoted to defining the plasticizer type and concentration and the polymer/curing agent ratio required to meet the program objectives. This study was conducted with the one-gallon horizontal blade mixer and several batches of propellant were made to evaluate the effects of various concentrations of DOA and TP-90B plasticizers at polymer/curing agent (P/CA) ratios of 1/.95 and above on tensile and processing properties of TP-H7038 propellant. The curing agent imine/epoxide (I/E) ratio utilized in most of these mixes was 3.8/1. The formulations evaluated were:

	% DOA						% TP-90B				
	1	2	2	3	3	3	1	2	2	2	3
P/CA Ratio	1/.83	1/1	1/1.1	1/1	1/1.1	1/1.2	1/1	1/.95	1/1	1/1.1	1/1
I/E Ratio	5/1 (Baseline)	3.8/1					3.8/1				5/1

JANNAF plastic gauge tensile data over the temperature range from +130°F to -65°F were obtained on each formulation. These data along with strain endurance data were utilized to construct a failure boundary for each formulation. A comparison of the failure boundaries for each family of propellants was made with the failure boundary of the baseline TP-H7038 propellant. These data are presented on Figures 1 through 5 and show that the formulations containing 2% TP-90B with polymer/curing agent ratios of 1/.95 and 1/1 exhibited the best tensile properties when compared with TP-H7038.

The viscosity data for the various formulations are presented in Table 1 and show that the lowest viscosity was obtained with TP-90B.

An alternate approach was evaluated as a means to meeting the program objectives. This approach utilized the basic TP-H7038 (1% DOA) propellant formulated at a polymer/curing agent ratio of 1/1 with a monofunctional imine added to the binder system to control binder crosslink density. The material selected for this study was a monofunctional aziridine produced by Dow Chemical. The material is N-phenethylaziridine which has the following structure.



This material was blended with MAPO to produce imine functionalities of 2.2 and 2.4 and were evaluated in one gallon batches of propellant. The results of this evaluation are presented on Figure 6 and show the effects of the various concentrations of the monofunctional material on the failure boundary of TP-H7038 propellant. The best tensile properties were obtained with the 2.2 functionality material; however, the overall strain capacity of the propellant was lower than the baseline TP-H7038. The processing of the formulation containing the 2.2 functionality imine was more difficult than the baseline TP-H7038. The viscosity of the mix containing the 2.2 functionality material was 32 kp compared to 18 kp for the baseline TP-H7038 propellant and 16 kp for the formulation with 2% TP-90B at a P/CA of 1/1.

Based on the data obtained from this phase of the program, the formulation containing 2% TP-90B and a polymer/curing agent ratio of 1/1 was selected for the Phase II study. The curing agent ratio (imine/epoxide, I/E) to be utilized was 3.8/1.

Phase II - Ballistic Properties

During this phase of the program the selected formulation was evaluated in ballistic test motors along with the baseline TP-H7038 propellant to evaluate the effects of replacing the 1% DOA with 2% TP-90B on propellant burning rate. The five-gallon vertical mixer was utilized in this phase of the study to provide the required ballistic and physical property samples, and to evaluate scale-up effects. Mix T-188 of the baseline TP-H7038 propellant and Mix T-243 of the selected formulation (with 2% TP-90B) were processed without difficulty. In fact, the processing properties of Mix T-243 were excellent with an end-of-mix viscosity of 7.2 kp obtained. The TX3-1 burning rate versus pressure relationships for these formulations are presented on Figure 7 and show there is no significant difference in the burning rate characteristics of the two propellants.

Tensile properties were also obtained for these formulations, and the data presented on Figure 8 shows the overall strain capacity of the formulation containing 2% TP-90B to be superior to the baseline TP-H7038 propellant.

Phase III - Scale-Up, Characterization, and Aging

The formulation evaluated in Phase II met the tensile and ballistic property requirements of the program; therefore, it was given the designation of TP-H7070 and was scaled up to the 420-gallon mixer for further evaluation This mix was made to demonstrate the practicality of producing and handling the selected composition on a large scale and to provide propellant for characterization and aging tests.

Mix L-212 (420-gallon vertical mixer) of TP-H7070 propellant was made on January 12, 1973. This selected formulation, with 2% TP-90B as the plasticizer and a polymer/curing agent ratio of 1/1, was otherwise similar to the standard TP-H7038 propellant in respect to solids. The ratios of ammonium perchlorate particles used were 45% special coarse ($\approx$400 microns)/27.5% unground ($\approx$200 microns)/27.5% ground ($\approx$17 microns). End-of-mix viscosity was 8.6 kp at 136°F. Effective casting life (time to 40 kp) was in excess of 16 hours (last reading, 25.7 kp at 13 1/2 hours).

Characterization - Ballistic Properties

The ballistic properties characterization was devoted to testing TX3-1 motors over a wide pressure range at temperatures of +130, +70, and -30°F.

The results from these tests are presented on Figure 9 and show the required burning rate of 0.39 in/sec @ 1000 psia was obtained. The measured π_k and σ_k values obtained from these tests are as follows:

π_k (-30 to +130°F)	0.103%/°F
σ_k (-30 to +130°F)	0.092%/°F

Characterization - Bond Properties

A set of composite adhesion and peel samples were also loaded with TP-H7070 propellant from Mix L-212. Tests were made at -30, 77, and 130°F. These data are reported in Table 2. The composite adhesion values were acceptable. Peel bond values were lower than expected and are considered marginal for use in the SAM-D motor. No explanation can be given for these low values; therefore, additional bond work would be required before this system could be used in a motor.

Characterization - Physical Properties

A complete physical property characterization study was conducted with the selected propellant as described below:

The objective of this phase of the program was to define the mechanical response and failure characteristics of TP-H7070, the CTPB propellant selected as the back-up to the primary HTPB propellant for the SAM-D motor. This characterization provides data for the predictive structural analysis of the motor over its temperature range of operation. Included in the characterization are input parameters for the stress analysis as well as a definition of the failure characteristics of the propellant in terms of design allowable stress and strain conditions. These failure characteristics have been defined in uniaxial tension and makes use of the principle of time-temperature equivalency for thermo-rheologically simple materials and particularly, the quantitative relationship between rate and temperature effects on polymers set forth by Williams, Landel and Ferry.[1]

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[1]M. L. Williams, R. F. Landel and J. D. Ferry, "The Temperature Dependence of Relaxation Mechanisms in Amorphous Polymers and Other Glass-Forming Liquids". Journal American Chemical Society, 77, 3701-3707 (1955).

The propellant for this characterization study was obtained from pressure cast samples from a 420-gallon mix, L-212. The tensile tests, in general, were conducted on Instron test machines with controlled crosshead velocity of $\pm 0.1\%$ and a load accuracy of $\pm 0.5\%$. Temperature control is maintained to within $\pm 2^{o}F$ with environmental conditioning chambers.

During the preparation and handling of the test specimens, the laboratory temperature was maintained at $+77^{o}F \pm 5^{o}F$ and the relative humidity was no greater than 50%.

Material Response Characterization

Constant Strain Rate Tensile Tests

The purpose of these tests was to define the response characteristics of the propellant in uniaxial tension. Constant strain rate tests of ICRPG Class B specimens were conducted at crosshead separation velocities of 0.2, 2.0, and 20.0 in/min at temperatures of -100, -80, -70, -65, -50, -30, 0, 20, 40, 60, 77, 130, and $160^{o}F$. Three replicate specimens were tested at each test condition. Strains were measured with plastic gauges.

The determination of the glassy modulus of the propellant was conducted at $-150^{o}F$. For these tests Class C JANNAF specimens were used and a gauge length selected based on the distance between the centers of radius of the flared ends of the specimens. This gauge length was selected because the propellant is extremely rigid at this temperature and very little, if any, jaw flow occurs. These tests were conducted at two strain rates and an average value of 176,000 psi was obtained for glassy modulus.

The constant strain rate uniaxial test data were utilized to determine the magnitude of the time-temperature shift required for TP-H7070 propellant. This factor was obtained by empirically shifting data obtained at various temperatures and strain rates. Maximum stress was the tensile property parameter used for determining the shift factor and was reduced to a reference temperature of $298^{o}K$ ($+77^{o}F$) and plotted as a function of the logarithmic strain rate as shown on Figure 10. The amount of shift along the logarithmic strain rate axis required to superpose each pair of stress curves is then determined and the total required shift obtained by addition. The total shift required for TP-H7070 propellant was 11.30 which corresponds to a log a_T (WLF shift factor) of 11.30 required to superpose data at the two temperature extremes. Having determined the shift factor, the Williams-Landel-Ferry equation in its usual form* was used to calculate the reference temperature of the propellant as follows.

Two simultaneous equations for test temperature extremes T_1 and T_2 were set up and since the total shift required between the two temperature extremes is known, the following equation was derived:

$$\log a_{T_1} - \log a_{T_2} = \frac{-8.86\,(T_1 - T_s)}{101.6 + (T_1 - T_s)} - \frac{8.86\,(T_2 - T_s)}{101.6 + (T_2 - T_s)} = 11.30$$

Substitution of the appropriate test temperatures into the above equation and solving for T_s yielded a value of 244°F for TP-H7070.

The next step in calculating the mechanical response of TP-H7070 propellant was to superpose all of the stress-strain curves obtained by testing at the various strain rates and temperatures into a master stress-strain curve. Individual stress-strain points at strain increments of 2.5, 5.0, 7.5 and 10% were calculated from each specimen tested. These data were used to plot a master stress-strain curve which is a plot of the logarithm of the temperature-corrected stress divided by the temperature reduced strain rate versus the logarithm of the decimal strain divided by the temperature reduced strain rate (Figure 11).

The glassy and equilibrium moduli are also included on Figure 11 and are straight lines of unit slope on the full-logarithmic scale. The equilibrium modulus line is simply displaced to the right (toward longer times) from the glassy modulus line and a value of 129 psi was obtained from stress relaxation tests. The data obtained from the constant strain rate tests lie along a line (representing the relaxation modulus) which connects the glassy modulus and equilibrium modulus lines.

The slope of the master stress-strain curve was used to calculate a relaxation modulus for TP-H7070 propellant and these data are presented on Figure 12. This is a plot of the logarithm of the time-dependent relaxation modulus versus the logarithm of time at the reference temperature of 244°K. The curve has been generalized by non-dimensionalizing time in terms of the shift factor a_T.

$$^{*}\log a_T = \frac{-8.86\,(T - T_s)}{101.6 + (T - T_s)}$$

The accuracy of the relaxation modulus curve as calculated from the master stress-strain curve was checked with the Blatz[2] modified power law. This equation relates modulus at any time to the glassy modulus, equilibrium modulus, the relaxation time of the material and β which is the slope of the linear portion of the relaxation modulus curve. As shown on Figure 12, excellent agreement was obtained and the modified power law representation of the mechanical response of TP-H7070 propellant can be expressed as follows:

$$E_r = \frac{E_g - E_e}{(1 + t/\tau)^{-\beta}} + E_e$$

where: E_r = relaxation modulus; $\beta = -0.169$

E_g = 176,000 psi; $\tau = 3.62 \times 10^{-13}$

E_e = 129 psi; t = time at 244°K or t/a_t

Hydrostatic Compressibility Tests

The compressibility of TP-H7070 propellant was measured on two replicate specimens as a function of pressure up to 2,000 psig. The sample consists of a three-inch cube of propellant whose volume is measured by displacement. The samples are coated with Latex rubber and placed in a compressibility chamber containing water. The chamber is pressurized with nitrogen gas and the change in the volume of water and the specimen is measured by means of an external situated servomanometer. The tests were conducted at +77°F.

The compressibility of the propellant as a function of pressure is shown on Figure 13. An average bulk modulus of 333,000 psi was obtained for TP-H7070 propellant which is a typical value for highly-loaded composite propellants.

Thermal Expansion Tests

Thermal coefficient of expansion of the propellant was measured using an experimental set-up similar to that described in Section 4.9.1 of the ICRPG

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[2] M. L. Williams, P. J. Blatz and R. A. Schapery, "Fundamental Studies Relating to Systems Analysis of Solid Propellants". Graduate Aeronautical Laboratory, California Institute of Technology, Report Number SM6 1-5, (Feb. 1961).

Testing Manual. Two replicate determinations of thermal coefficient of expansion were made by cooling the propellant. These determinations were made using specimens approximately three inches long by about one-half inch in diameter with a linear variable differential transformer following the motion of the specimen as it is cooled and driving the Y-axis of an X-Y plot. The X-axis of the plotter is compensated for use wtih a copper-constantan thermocouple so that this axis is a direct plot of temperature. The rate of cooling was approximately $2^{o}F/3$ mins. and the temperature range covered was from $+150^{o}F$ to $-150^{o}F$. The apparatus used is capable of measuring change in length of two specimens simultaneously. A copper specimen serves as a reference standard. Two replicate determinations of the coefficient of thermal expansion were made and the data are presented on Figure 14. A nominal value of 5.62×10^{-5} in/in/^{o}F was obtained over the temperature range from $+110^{o}F$ to $-140^{o}F$.

Thermal Conductivity

The thermal conductivity of the propellant was determined using a Colora Thermoconductometer. The Colora Thermoconductometer is based upon the method of Schroeder for determining the thermal conductivity of solids. The thermoconductometer requires time measurements only and does not involve any calometric measurements. A cylindrical sample of the material to be tested, approximately 1/8 inch thick by 3/4 inch diameter, is brought into contact with the vapors from a boiling liquid, in this case, water. The heat transferred through the sample to the "cold side" is used to boil a lower-boiling liquid, in this case, benzene. The vapors of the lower boiling liquid are condensed and the rate of formation of condensate is determined. This rate of distillation is proportional to the rate of heat transfer through the sample.

Calibrated samples with known heat resistances are measured with the selected liquid pair in order to determine the relationship between thermal resistance and rate of distillation.

Using a calibrated curve from the above tests, the thermal resistance of the unknown sample is determined from the time required to distill one millimeter of the low boiling liquid; the thermal conductivity of the material is then calculated from its dimensions and its thermal resistance by means of the equation:

$$\lambda = \frac{h}{RF} \text{ cal/cm sec}^{o}\text{C}$$

in which

R = Heat resistance of sample, sec°C/cal

h = Sample height, cm

F = Sample cross-section, cm^2

An average thermal conductivity of 1.292×10^{-3} cal/cm-sec°C was obtained for TP-H7070 propellant.

Specific Heat

Specific heat was determined by using a weighed specimen (1" x 1" x 2") which is lowered from a steam jacket into a calorimeter containing a measured quantity of water at 25°C (+0, -1°C). The initial temperature of the sample is assumed to be that of saturated water vapor at the existing barometric pressure and is determined by reference to steam tables. The temperature of the water is read to hundredths °C every one-half minute with a mercury in glass thermometer. The final temperature of the system is corrected for heat lost by radiation. The heat gained by system is set equal to that lost by the specimen and the equation solved for the specific heat of the specimen. Three replicate samples were tested and an average value of 2.835×10^{-1} cal/gm°C was obtained.

Failure Behavior Characterization

Constant Strain Rate Tensile Tests

The elimination of temperature and rate from the failure characteristics of materials such as propellant can be accomplished by simply plotting temperature reduced tensile strength versus strain at maximum stress. The characterization of failure in elastomeric materials by means of such a stress-strain failure boundary was first proposed by Smith,[3] who suggested that such a boundary could be independent of path; that is, that a stress-strain combination which lay on the failure boundary of an elastomeric material would result in failure of the material regardless of how the stress-strain combination was applied.

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[3] T. L. Smith, "Ultimate Tensile Properties of Elastomers, I. Characterization by a Time and Temperature Independent Failure Envelope". Journal Polymer Science, Part A, 1, 3597-3615 (1963).

The failure boundary for TP-H7070 propellant was constructed from the data obtained from the constant strain rate uniaxial tensile tests conducted at temperatures ranging from -100°F to +160°F and crosshead speeds of 0.2, 2.0 and 20.0 in/min. The failure boundary is shown on Figure 15 and shows that all the failure points lay along the line which represents the failure envelope of the material. Within this envelope lie all the stress-strain conditions that can be withstood by the propellant without failure; however, the material will presumable fail if it is subjected to any stress-strain conditions outside the boundary.

Strain Endurance Tests

In order to evaluate the lower limit of permissible strain for very low stress levels, strain endurance tests were employed. In this test, JANNAF tensile specimens of propellant are subjected to various constant strain levels with three replicate specimens tested at each level. For most viscoelastic materials such as CTPB propellants, failure will occur in relatively short times if it does occur. The highest strain level at which none of the three specimens tested shows any defect for 14 days is defined as the strain endurance capability of the propellant. A nominal strain endurance level of 22% was obtained for TP-H7070 propellant and as shown on Figure 15 this strain level agrees quite well with the lower end of the failure boundary.

Aging Program

This aging program was designed as a one-year study which had the capability for some phases to be extended to five; however, because of the behavior of the propellant during high temperature aging for one year, the program is not being continued.

The initial storage items in this study were: prepared tensile specimens which were stored (and tested without being allowed to warm) at -30 and -50°F to determine the susceptibility of TP-H7070 to undergo binder phase change (or similar phenomenon) during low temperature exposure; and bulk sealed samples that were aged at ambient and 130°F. Tensile tests (and strain endurance determinations where failure boundary testing was accomplished with the bulk sealed samples) were conducted to follow changes in physical properties with time.

Propellant samples which were actually stored and tested are as follows:

Storage Item	Storage Temperature	Storage Time (Months)[b] 0	1	2	3	4	5	6	10	12
Bulk Sealed	130°F	X	X	X	X	X	X	X	X	X
Bulk Sealed	Ambient	X	X		X			X	X	X
Specimen	-30°F	X	X	X	X			X		
Specimen	-50°F	X	X	X	X			X		
Gradient[a]	130°F				X			X		

a. One surface exposed to nitrogen gas/desiccated (1-2g. Molecular Sieves) atmosphere.

b. X = Additional storage items for additional information.

Twelve months of storage and testing were accomplished, which, as indicated above, completes this aging program.

Low-Temperature Specimen Storage

In this study, prepared tensile specimens of TP-H7070 were subjected to -30 and -50°F storage for periods up to six months. The tensile data generated during this time (Tables 3 and 4 ; Figures 16 and 17) show no significant change in strain capability for the propellant at -30°F. (The indicated minor decrease in tensile strength found in the six-month test results is attributed to testing variables.) The propellant did, however, experience a minor to moderate reduction in elongation at -50°F.

Bulk Sealed Storage

Complete failure boundary testing (JANNAF plastic gauge samples at 160, 130, 77, 40, 0, -30, -50, and -65°F as a minimum) with strain endurance determinations were accomplished at each test interval. After it became apparent that the propellant was not going to exhibit the desired improved storage stability at 130°F, the decision was made to test a sample at the 10-month storage interval, but the number of test temperatures were reduced to five (130, 77, -30, and -50°F) so that only one bulk sealed sample was required

The results that were obtained during twelve months of bulk sealed storage at ambient show the development of an expected minor post cure involving increased tensile strength, decreased elongation, and decreased strain endurance (Table 5; Figures 18 through 23). The minor changes that the post cure caused in propellant physical properties at 77°F can be seen in the tensile properties versus time plot on Figure 18. The shift in the failure boundary that has occurred with the development of the minor post cure is quite evident in the failure boundary plots on Figures 19 through 23.

TP-H7070 propellant experienced a considerable decrease in tensile strength when aged in bulk sealed form at 130°F. At the end of twelve months, the reduction in maximum stress values was greater than 50% at the higher test temperatures. The test results obtained through the twelve months of exposure are found in Table 6. Although the softening became apparent after two to three months, the data points continued to provide a good fit to the "0" time failure boundary through four months of storage; however, the changes that occurred after this time caused a shift to the right in the lower part of the failure boundary which is formed by the higher temperature tests and strain endurance (Figures 24 through 31).

The softening that has been experienced with this mix of TP-H7070 (L-212) at 130°F is comparable to that obtained with TP-H7038 under the same conditions. This fact is quite evident when the 77°F test results from TP-H7070 (Figure 32) are compared with those generated in two TP-H7038 propellant aging programs that were conducted with Mixes N-432 and L-32 (Figures 33 and 34).

As reported previously, the degradation obtained with TP-H7070 at 130°F was unexpected, and was investigated. Since internal moisture was considered to be the most likely cause of the poor thermal stability of the propellant (with the special coarse perchlorate being the most probable source of the internal moisture), one part of the investigation involved the use of desiccant during storage in an attempt to improve the high temperature stability. It was demonstrated in the two TP-H7038 aging programs that improved thermal stability could be achieved by desiccation (Mix L-32, Table 7, with desiccation; Mix N-432, Table 8 and Figures 35 and 36, no desiccation, and Table 9 and Figures 37 and 38, with desiccation). However, in those programs, the amount of desiccant employed was much greater than that used in the TP-H7070 study. In the TP-H7070 investigation, desiccated gradient samples (1.0 to 2.0g. of desiccant which was based upon a recommended 200g. for the SAM-D motor) were placed in storage at 130°F. Gradient tensile testing at 77°F was then accomplished after three and six months of storage. The results, as found in Table 10 and on Figure 39, show that this amount of desiccant did not improve the thermal stability of the propellant. The six-month test data show a 30 to 35% reduction in tensile strength which is identical to that found in the 77°F test results after six months of bulk sealed storage (Table 6).

Since it now appears that the probable cause for the poor thermal stability of the TP-H7038 family of propellants was due to internal moisture in the special coarse, another area of investigation involved an effort to formulate an acceptable propellant without special coarse ammonium perchlorate. This will be discussed more fully under Phase IV below.

The following conclusions were drawn from the one-year TP-H7070 propellant aging program:

a. Low temperature specimen storage results show no significant change in strain capability for TP-H7070 propellant during six months of exposure to -30°F; at -50°F, however, a minor to moderate reduction in elongation occurred.

b. The propellant experienced an expected minor post cure (increased tensile strength, decreased elongation, and decreased strain endurance) during twelve months of bulk sealed storage at ambient.

c. TP-H7070 exhibited an unexpected decrease in tensile strength when stored in bulk sealed form at 130°F. This phenomenon (which apparently is caused by internal moisture, with the special coarse perchlorate being the most likely source of the moisture) was investigated.

d. In one part of the investigation, desiccation (with the amount of desiccant being based upon the recommended 200g. for the full-scale SAM-D motor) did not improve the thermal stability of the TP-H7070 formulation.

e. An effort was made to formulate an acceptable propellant that did not contain special coarse perchlorate.

Phase IV - Reformulation, Scale-Up, and Aging

The TP-H7070 propellant developed and tested under Phases I through III exhibited equally poor high temperature aging stability as the initial TP-H7038 propellant. These data indicated that the probable cause of the premature tensile property degradation is moisture, and specifically the high internal moisture content of the special coarse oxidizer. Therefore, the TP-H7038 propellant was reformulated to delete the special coarse AP. It was theorized that the propellant moisture content could be significantly decreased if 200 micron (unground)

AP was substituted for the special coarse (420 micron) AP fraction. Some recent work with TP-H7036 propellant, which is similar to TP-H7038, showed that the propellant could be successfully processed without 420 micron size AP and with low percentages of ground AP, a step necessary in order to maintain a sufficiently low burning rate. A change from a nominal 16 micron aluminum particle size to a nominal 30 micron aluminum particle size also helped significantly in keeping the burning rate low on the TP-H7036 propellant.

A 4 1/2-gallon mix, R1065, of modified TP-H7038 propellant was made using a 80/20 ratio of unground/ground AP, a 1/0.80 polymer/curing agent ratio, and 30 micron aluminum. The mix had acceptable processing properties, uncured strand rate similar to TP-H8208, and excellant tensile properties. Next, another 4 1/2-gallon mix, R1066, was made using a 1/0.83 P/CA ratio and the same AP ratio and aluminum as the first mix. The second mix had acceptable processing properties, near-target TX-3 burning rate, and adequate tensile property values. However, the 1/0.83 P/CA mix had only 22 percent strain endurance, as opposed to 34 percent measured for the previous mix (1/0.80) and 30 percent (typically) for the earlier version of TP-H7038. Table 11 compares processing, ballistic and tensile data from the early (trimodal AP) TP-H7038 version, TP-H7070 (Phase III), TP-H8208 (HTPB), and the modified (bimodal AP) TP-H7038. The results demonstrate that the bimodal version of TP-H7038 can: (1) be processed; (2) provide adequate tensile properties; and, (3) yield target burning rate.

The modified (bimodal AP) TP-H7038 propellant was scaled up to a 50-gallon mix, W-24, for further evaluation. The 50-gallon vertical mixer was used since insufficient funds were available for a larger 420-gallon mix, and since sufficient samples could be obtained for the short time remaining on the program for aging evaluation. This mix was made to demonstrate the practicality of processing and handling the selected composition on a larger scale, to provide propellant for ballistic and tensile property evaluation, and to provide samples for the abbreviated aging program.

Mix W-24 was made on November 15, 1974, using a 80/20 ratio of unground/ground AP oxidizer, 30 micron aluminum, and a 1/0.80 P/CA ratio at a 5/1 imine-to-epoxide curing agent ratio. Since this was the first 50-gallon mix of this type propellant, the old TP-H7038 procedures for the 420-gallon vertical mixer were adapted to the capabilities of the 50-gallon mixer. The resulting propellant appeared to be well-mixed and all planned samples were cast. End-of-mix viscosity was 20.7 kp at 124°F.

Ballistic Properties

As discussed previously, the use of special coarse oxidizer was at first considered necessary to achieve a sufficiently low burning rate. This belief held until recent work indicated high ratios of unground-to-ground oxidizer could provide the desired low burning rate while maintaining propellant processability and good tensile properties. Under this propellant reformulation effort, a 80/20 ratio of unground/ground oxidizer was utilized in the two 4 1/2-gallon mixes. As listed previously in Table 11, the burning rate obtained on Mix R1066 was below target. No attempt was made to adjust the oxidizer ratio on scaling to the 50-gallon vertical mixer since scale factors between the two mixers for this type propellant were unknown. Also, if a burning rate below target was obtained on the 50-gallon mix, adjustments to raise the burning rate for future mixes would be in the direction that would provide better propellant processing and tensile properties.

1 X 3 ballistic test motors loaded from Mix W-24 were tested using the same hexagonal test pattern used for SAM-D motor loading mixes. Test results and calculated ballistic properties are given in Table 12. These results show that the burning rate achieved was approximately 5 percent below target. This was encouraging since it indicates a wider range of burning rate tailoring ability while still achieving the desired burning rate and good processability.

Tensile Properties

A simplified failure boundary (tests at 2 in/min. crosshead speed only) was constructed for the modified TP-H7038 propellant from Mix W-24. This is shown on Figure 40, and the tabular results are given in Table 13. A nominal strain endurance level of 30% was obtained. In general, the tensile properties obtained are considered to be quite good, and are considerably better than those obtained with the TP-H7070 propellant discussed under Phase III.

Aging Program

Sufficient samples were obtained from Mix W-24 to do minimal aging for one year; however, only six months were available for testing. The planned allocation of the samples obtained is outlined in Table 14. As noted, the evaluation included bulk sealed and bulk gradient storage at ambient and 130°F. Failure boundary testing was accomplished with the bulk sealed samples. The gradient samples, which were aged under nitrogen with and without desiccant (with the amount of desiccant being based upon the recommended 200g. for the full-scale SAM-D motor), were tested (tensile) at 77°F to determine the extent to which surface-interior physical property gradients occurred.

Six months of storage and testing were completed with the following results obtained.

Bulk Sealed Storage

The modified TP-H7038 formulation has experienced an expected slight reduction in strain, with no significant change in stress, during the six months of bulk sealed storage at ambient. Tensile results, as presented in Table 15 and on Figures 40 through 42 show essentially the same behavior that TP-H7070 propellant exhibited under the same storage conditions. Even though there was a minor decrease in strain values at most of the test temperatures, the only change seen in the six-month failure boundary was a slight shift to the left for the lower portion.

Six months of exposure to the elevated temperature of 130°F, in bulk sealed form, has caused the modified TP-H7038 propellant to undergo a minor reduction in tensile strength, with no significant changes in strain values, at most of the failure boundary test temperatures (Table 16, Figure 43). However, minor decrease in stress values has caused no appreciable change in the failure boundary. This fact is quite obvious when the failure envelopes found on Figures 44 through 46 are compared to that for the unaged propellant (Figure 40).

Bulk Gradient Storage

The bulk gradient tensile results from the ambient storage contained some scatter, and there was some sample to sample variation. However, an overall review of the data showed about the same behavior pattern as obtained with the ambient bulk sealed storage (Tables 17 and 18, Figures 47 through 52). There was a minor reduction in strain with no appreciable change in stress. There was also no development of surface-interior physical property gradients, and no detrimental changes due to desiccation. This last statement could possibly be challenged when the indicated decrease in strain obtained for the six-month desiccated sample is considered (Table 18, Figure 51). However, this indicated change was apparently caused by sample to sample variation, because low strain values were obtained throughout the sample. The diffusion rate of moisture is such that the whole sample could not possible be affected by external desiccation within six months. This is, therefore, the

the reason for stating that desiccated storage at ambient has resulted in no detrimental changes.

Gradient storage under nitrogen at 130°F in the absence of desiccant caused the propellant to experience a surface-interior physical property gradient due to decreased tensile strength on and near the exposed surface. This gradient first became apparent after two months of exposure and, at the end of six months, progressed to the point that the propellant has been effected to a depth of two inches (Table 19, Figures 53 through 58). However, the interior propellant beyond the first two inches has, at the end of six months, undergone only a minor decrease in tensile strength of about the same magniture as that experienced by the 130°F bulk sealed samples.

The results contained in Table 20 and Figures 59 through 62 show that desiccation will definitely improve the high temperature (130°F) stability of the modified TP-H7038 propellant. In the presence of desiccant, there was no apparent surface-interior physical property gradient due to decreased stress and strain on and near the surface. As expected, however, the plot of the six-month data showed a minor reduction in the tensile strength of the interior propellant. The indicated minor decrease of tensile strength on and near the surface of the six-month sample probably means that the desiccant in this particular container was essentially depleted.

Comparison of Storage Stability at 130°F

The storage stablity of the various CTPB back-up propellants for SAM-D was compared after aging at 130°F. This comparison included the original CTPB propellant with special coarse oxidizer, TP-H7038; the propellant developed under Phases I and II of this program, TP-H7070; and the modified TP-H7038 developed herein (under Phase IV) with no special coarse oxidizer. (Additional information on these formulations in respect to oxidizer content, I/E ratio, and P/CA ratio can be obtained by referring to Table 11).

Although removal of the special coarse perchlorate from the modified TP-H7038 propellant did not prevent softening (decreased tensile strength) of this formulation, there was some improvement. A comparison of the results from Mix W-24, modified TP-H7038, with those obtained from the other CTPB propellants (Mix L-212, TP-H7070; Mixes L-32 and N-432, original TP-H7038) was somewhat complicated by the fact that the four aging studies on these mixes were not conducted in the same manner; however, sufficient comparative data were available for general conclusion to be drawn regarding the benefits of the formulation changes. The results that were available, and the ranking (best to poorest) of the four mixes of propellant after six months at 130°F under each storage condition are presented in Table 21 (figures noted on this table give location of data used in comparison).

Even though, in the majority of the cases, the differences in the mechanical properties of the propellant from the four mixes were rather small, it will be noted from Table 21 that in no instances were the properties of Mix W-24 inferior to any of the other three mixes. The most conclusive evidence for the high-temperature superiority of the propellant from Mix W-24 was found in the bulk sealed data. At the end of six months, the modified TP-H7038 formulation had definitely experienced less degradation (reduction in tensile strength) than the other three mixes. The bulk sealed environment constitutes the best condition for evaluating the storage stability of propellants because the only variable factors involved are time and temperature.

In respect to the other storage conditions, the tensile properties of the surface slab from bulk gradient samples stored under a nitrogen atmosphere (without desiccant) show that the modified TP-H7038 propellant (Mix W-24) changed at a slightly slower rate than the regular TP-H7038 propellant (Mix N-432). The tensile properties through the bulk gradient samples stored under nitrogen for six months show that, although the surface slabs were affected to about the same degree, the modified TP-H7038 propellant was affected to a lesser depth than was the regular TP-H7308 (Mix N-432). Similar data was not available for mixes L-32 and L-212.

For the bulk gradient samples stored under a nitrogen atmosphere with desiccant, the tensile properties of the surface slabs (based on tensile strength) indicate an equal ranking for the modified (Mix W-24) and regular (Mix N-432) TP-H7038 propellants. The reduced strain values for the N-432 mix were probably caused by overdesiccation. (Excessive desiccant for size sample was used with both Mix N-432 and L-32). The physical properties through the bulk gradient samples stored under nitrogen with desiccant show an equal, but higher ranking for Mixes W-24 and L-32 than for Mix L-212 and N-432. Surface properties of Mix N-432 were superior to those for Mix L-212 apparently because of the excessive amount of desiccant used with Mix N-432.

In summary, the following conclusions were drawn from the six months modified TP-H7038 propellant aging program.

a. Removal of the special coarse ammonimum perchlorate oxidizer from the TP-H7038 propellant formulation resulted in an improvement in the physical properties and in the high-temperature (130°F) storage stability. This was indicated by the bulk sealed sample physical properties and the depth to which surface-interior properties were affected in bulk gradient samples stored under nitrogen.

b. The propellant experienced an expected slight reduction in strain, with no significant change in stress, during the six months of bulk sealed storage at ambient. This was also true for the bulk gradient samples, which also showed no development of surface-interior physical property gradients and no detrimental changes due to desiccation.

c. Gradient storage at 130°F in the absence of desiccant caused the propellant to experience a surface-interior physical property gradient due to decreased tensile strength on and near the exposed surface. However, the interior propellant (beyond the affected depth) underwent only a minor decrease in tensile strength of about the same magnitude as that of the bulk sealed samples. In the presence of desiccant, no surface-interior physical property gradient was apparent, but an expected minor reduction in tensile strength of the interior propellant was shown.

d. With the improvements shown, the modified formulation without special coarse oxidizer would be the better choice from the CTPB propellants for the SAM-D motor if, for some highly unlikely reason, it became necessary to substitute a CTPB propellant for the present HTPB propellant.

TABLE 1

EFFECT OF VARIOUS PLASTICIZER TYPES AND CONCENTRATION ON THE VISCOSITY OF TP-H7038 PROPELLANT

	% DOA						% TP-90B				
	1	2	2	3	3	3	1	2	2	2	3
P/CA Ratio	1/.83	1/1	1/1.1	1/1	1/1.1	1/1.2	1/1	1/.95	1/1	1/1.1	1/1
I/E Ratio	5/1	3.8/1	3.8/1	3.8/1	3.8/1	3.8/1	3.8/1	3.8/1	3.8/1	3.8/1	3.8/1
Mix # 14Q	142 (Baseline)	64	65	103	62	63	86	186	104	87	114
Viscosity (kp/°F)											
End of Mix	14/138	12/138	10.8/138	10/137	10/138	10/136	14/137	12/140	12/139	10/139	8/139
After Deaeration	18/135	16.8/128	16/136	14/135	16/132	16/131	20/136	18/131	16/138	14.8/138	10.8/135

TABLE 2

BOND OF TP-H7070 PROPELLANT TO TL-H715A LINER

PROPELLANT MIX NO. L-212(1)

LINER MIX NO. RL-02190(2) 2-13-72

TEST TEMPERATURE: 77°F

STRAIN RATE: 1 IN/MIN

Test Temp. °F	Composite Adhesion		Peel		
	Load	Failure (3)	Initial pli	Avg. pli	Failure (3)
-30	291	5P + TCP	21.1	21.8	5 TCP
77	134	4P + TCP	7.4	6.9	5 B
130	63.8	2TCP, 3P+TCP	4.2	4.0	5 B

(1) Propellant Physical Properties for Mix L-212 at 77°F

Modulus: 1093
Strain at Max. Stress: 27%
Stress, Max. 179

(2) Liner was precured 3 hrs. at 170°F prior to propellant being cast. Penetrometer hardness at end of precure: 165 mm X 10^{-1}, no weight.

(3) The number of samples tested and the mode of failure are indicated: P= propellant, TCP= thin coat of propellant; B= bond.

TABLE 3

EFFECT OF -30°F STORAGE ON THE PHYSICAL PROPERTIES*

OF TP-H7070 PROPELLANT STORED IN SPECIMEN FORM

(Mix L-212)

Storage Time (months)	Test Temperature (°F)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	-30	2997		349		0.366		0.417	
1 wk.	-30	2951	0.98	335	0.96	0.357	0.98	0.405	0.97
2 wks.	-30	2846	0.95	327	0.94	0.352	0.96	0.397	0.95
1	-30	3066	1.02	334	0.96	0.356	0.97	0.415	1.00
2	-30	3151	1.05	322	0.92	0.352	0.96	0.406	0.97
3	-30	2887	0.96	327	0.94	0.353	0.96	0.411	0.99
6	-30	2362	0.79	296	0.85	0.364	0.99	0.408	0.98

*Corrected JANNAF

TABLE 4

EFFECT OF $-50^{\circ}F$ STORAGE ON THE PHYSICAL PROPERTIES*

OF TP-H7070 PROPELLANT STORED IN SPECIMEN FORM

(Mix L-212)

Storage Time	Test Temperature	Modulus		Maximum Stress		Strain at Maximum Stress		Strain at Cracking	
(months)	($^{\circ}F$)	(psi)	(E/E_o)	(psi)	(σ/σ_o)	(in/in)	(e/e_o)	(in/in)	(e/e_o)
0	-50	4361		445		0.410		0.471	
1 wk.	-50	5927	1.36	465	1.04	0.382	0.93	0.430	0.91
2 wks.	-50	5703	1.31	441	0.99	0.346	0.84	0.393	0.83
1	-50	5535	1.27	454	1.02	0.357	0.87	0.406	0.86
2	-50	6096	1.40	451	1.01	0.324	0.79	0.365	0.77
3	-50	6696	1.54	464	1.04	0.309	0.75	0.370	0.79
6	-50	7296	1.67	447	1.00	0.273	0.67	0.303	0.64

*Corrected JANNAF

TABLE 5

EFFECT OF AMBIENT TEMPERATURE STORAGE ON THE PHYSICAL* PROPERTIES OF TP-H7070 PROPELLANT STORED IN BULK SEALED FORM

(Mix L-212)

Storage Time (months)	Test Temperature (°F)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	160	867		133		0.241		0.249	
	130	973		146		0.238		0.247	
	77	1093		179		0.270		0.292	
	60	1259		188		0.257		0.275	
	40	1426		200		0.260		0.284	
	20	1518		221		0.266		0.287	
	0	1932		253		0.282		0.309	
	-30	3423		319		0.313		0.369	
	-50	5829		411		0.349		0.389	
	-65	10402		563		0.410		0.458	
	-70	11628		610		0.405		0.431	
	-80	13850		653		0.308		0.321	
	-100	36378		750		0.042		0.052	
1	160	1005	1.16	139	1.05	0.222	0.92	0.230	0.92
	130	1101	1.13	150	1.03	0.226	0.95	0.235	0.95
	77	1331	1.22	186	1.04	0.250	0.93	0.264	0.90
	40	1504	1.05	212	1.06	0.269	1.03	0.291	1.02
	0	2271	1.18	264	1.04	0.269	0.95	0.289	0.94
	-30	4284	1.25	349	1.09	0.309	0.99	0.354	0.96
	-50	7539	1.29	453	1.10	0.348	1.00	0.377	0.97
	-65	13004	1.25	615	1.09	0.372	0.91	0.391	0.85

*Corrected Strain Gage Data, Class C Specimens

Table 5 continued

EFFECT OF AMBIENT TEMPERATURE STORAGE ON THE PHYSICAL* PROPERTIES OF TP-H7070 PROPELLANT STORED IN BULK SEALED FORM

(Mix L-212)

Storage Time	Test Temperature	Modulus		Maximum Stress		Strain at Maximum Stress		Strain at Cracking	
(months)	(^oF)	(psi)	(E/E_o)	(psi)	(σ/σ_o)	(in/in)	(e/e_o)	(in/in)	(e/e_o)
3	160	1024	1.18	134	1.01	0.217	0.90	0.226	0.91
	130	1135	1.17	140	1.00	0.221	0.93	0.232	0.94
	77	1275	1.17	168	0.94	0.237	0.88	0.250	0.86
	40	1670	1.17	198	0.99	0.236	0.91	0.251	0.88
	0	2433	1.26	268	1.06	0.260	0.92	0.275	0.89
	-30	4455	1.30	342	1.07	0.280	0.89	0.312	0.85
	-50	9738	1.67	504	1.23	0.345	0.99	0.375	0.96
	-65	8854	0.85	535	0.95	0.360	0.88	0.396	0.86
6	160	1080	1.25	144	1.08	0.215	0.89	0.224	0.90
	130	1194	1.23	157	1.08	0.222	0.93	0.230	0.93
	77	1389	1.27	188	1.05	0.232	0.86	0.242	0.83
	60	1430	1.14	196	1.04	0.250	0.97	0.272	0.99
	40	1712	1.20	218	1.09	0.241	0.93	0.254	0.89
	20	1809	1.19	232	1.05	0.260	0.98	0.280	0.98
	0	2305	1.19	272	1.08	0.278	0.99	0.309	1.00
	-30	4332	1.27	355	1.11	0.302	0.96	0.345	0.93
	-50	7023	1.20	465	1.13	0.354	1.01	0.408	1.03
	-65	11937	1.15	580	1.03	0.361	0.88	0.390	0.85
	-70	13809	1.19	619	1.01	0.344	0.85	0.365	0.85
	-80	19110	1.38	682	1.04	0.236	0.77	0.253	0.79
	-100	49300	1.36	814	1.09	0.030	0.71	0.037	0.71

*Corrected Strain Gage Data, Class C Specimens

Table 5 concluded

EFFECT OF AMBIENT TEMPERATURE STORAGE ON THE PHYSICAL*
PROPERTIES OF TP-H7070 PROPELLANT STORED IN BULK SEALED FORM

(Mix L-212)

Storage Time (months)	Test Temperature (^oF)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_c)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
10	130	1420	1.46	162	1.11	0.202	0.85	0.213	0.86
	77	1633	1.49	199	1.11	0.231	0.86	0.249	0.85
	20	2041	1.34	254	1.15	0.256	0.96	0.280	0.98
	-30	5157	1.51	370	1.16	0.268	0.86	0.288	0.78
	-50	7626	1.31	485	1.18	0.343	0.98	0.372	0.96
12	160	1025	1.18	142	1.07	0.224	0.93	0.240	0.96
	130	1213	1.25	161	1.10	0.223	0.94	0.232	0.94
	77	1393	1.27	186	1.04	0.244	0.90	0.257	0.88
	60	1590	1.26	198	1.05	0.225	0.88	0.235	0.85
	40	1480	1.04	213	1.07	0.256	0.98	0.269	0.95
	20	1989	1.31	233	1.05	0.240	0.90	0.256	0.89
	0	2471	1.28	271	1.07	0.247	0.88	0.264	0.85
	-30	4217	1.23	344	1.08	0.312	1.00	0.357	0.97
	-50	8066	1.38	459	1.12	0.336	0.96	0.370	0.95
	-65	11819	1.14	596	1.06	0.398	0.97	0.433	0.95
	-70	13475	1.16	637	1.04	0.349	0.86	0.374	0.87
	-80	16875	1.22	673	1.03	0.240	0.78	0.255	0.79
	-100	37527	1.03	818	1.09	0.035	0.83	0.040	0.77

*Corrected Strain Gage Data,
Class C Specimens

TABLE 6

EFFECT of 130°F STORAGE on the PHYSICAL PROPERTIES*
of TP-H7070 PROPELLANT STORED in BULK SEALED FORM

(Mix L-2[illegible]2)

Storage Time (months)	Test Temperature (°F)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	160	867		133		0.241		0.249	
	130	973		146		0.238		0.247	
	77	1093		179		0.270		0.292	
	60	1259		188		0.257		0.27[illegible]	
	40	1426		200		0.260		0.284	
	20	1518		221		0.266		0.287	
	0	1932		253		0.282		0.309	
	-30	3423		319		0.313		0.369	
	-50	5829		411		0.349		0.389	
	-65	10402		563		0.410		0.458	
	-70	11628		610		0.405		0.431	
	-80	13850		653		0.308		0.321	
	-100	36378		750		0.042		0.052	
1	160	955	1.10	136	1.02	0.221	0.92	0.228	0.92
	130	956	0.98	148	1.01	0.229	0.96	0.235	0.95
	77	1197	1.10	180	1.01	0.253	0.94	0.274	0.94
	40	1370	0.96	205	1.03	0.264	1.02	0.282	0.99
	0	2039	1.06	266	1.05	0.300	1.06	0.338	1.09
	-30	4022	1.17	355	1.11	0.336	1.07	0.402	1.09
	-50	6763	1.16	464	1.13	0.383	1.10	0.437	1.12
	-65	10250	0.99	597	1.06	0.400	0.98	0.434	0.95

* Corrected Strain Gage Data,
Class C Specimens

Table 6 continued

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*
OF TP-H7070 PROPELLANT STORED IN BULK SEALED FORM

(Mix L-212)

Storage Time (months)	Test Temperature (°F)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
2	160	803	0.93	131	0.98	0.234	0.97	0.242	0.97
	130	1007	1.03	140	0.96	0.226	0.95	0.233	0.94
	77	1173	1.07	169	0.94	0.248	0.92	0.262	0.90
	40	1384	0.97	193	0.97	0.258	0.99	0.284	1.00
	0	2278	1.18	245	0.97	0.266	0.94	0.302	0.98
	-30	3959	1.16	331	1.04	0.316	1.01	0.379	1.03
	-50	6527	1.12	436	1.06	0.386	1.11	0.481	1.24
	-65	11911	1.15	586	1.04	0.384	0.94	0.429	0.94
3	160	738	0.85	111	0.83	0.236	0.98	0.243	0.98
	130	789	0.81	122	0.84	0.250	1.05	0.262	1.06
	77	959	0.88	140	0.78	0.250	0.93	0.265	0.91
	40	1233	0.86	169	0.85	0.266	1.02	0.283	1.00
	0	2199	1.14	229	0.91	0.282	1.00	0.323	1.05
	-30	4221	1.23	290	0.91	0.323	1.03	0.379	1.03
	-50	8931	1.53	445	1.08	0.358	1.03	0.405	1.04
	-65	8588	0.83	483	0.86	0.395	0.96	0.439	0.96
4	160	650	0.75	105	0.79	0.255	1.06	0.267	1.07
	130	766	0.79	115	0.79	0.246	1.03	0.256	1.04
	77	905	0.83	137	0.77	0.270	1.00	0.294	1.01
	40	1176	0.82	158	0.79	0.254	0.98	0.286	1.01
	0	2029	1.05	207	0.82	0.288	1.02	0.335	1.08
	-30	3676	1.07	257	0.81	0.282	0.90	0.345	0.93
	-50	5528	0.95	351	0.85	0.377	1.08	0.450	1.16
	-65	9445	0.91	504	0.90	0.400	0.98	0.440	0.96

*Corrected Strain Gage Data,
Class C Specimens

Table 6 continued

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*

OF TP-H7070 PROPELLANT STORED IN BULK SEALED FORM

(Mix L-212)

Storage Time (months)	Test Temperature (°F)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
5	160	595	0.69	99	0.74	0.266	1.10	0.282	1.13
	130	609	0.63	108	0.78	0.277	1.16	0.295	1.19
	77	753	0.69	129	0.72	0.287	1.06	0.314	1.08
	40	951	0.67	146	0.73	0.279	1.07	0.307	1.08
	0	1807	0.94	196	0.77	0.289	1.02	0.342	1.11
	-30	3482	1.02	253	0.79	0.318	1.02	0.363	0.98
	-50	6371	1.09	352	0.86	0.375	1.07	0.466	1.20
	-65	6825	0.66	392	0.70	0.363	0.89	0.414	0.90
6	160	442	0.51	78	0.59	0.243	1.01	0.258	1.04
	130	493	0.51	91	0.62	0.268	1.13	0.285	1.15
	77	696	0.64	121	0.68	0.275	1.02	0.303	1.04
	60	861	0.68	130	0.69	0.270	1.05	0.299	1.09
	40	915	0.64	139	0.70	0.280	1.08	0.329	1.16
	20	1127	0.74	152	0.69	0.284	1.07	0.323	1.13
	0	1653	0.86	173	0.68	0.300	1.06	0.352	1.14
	-30	3532	1.03	242	0.76	0.295	0.94	0.369	1.00
	-50	6419	1.10	342	0.83	0.348	1.00	0.445	1.14
	-65	10040	0.97	453	0.80	0.412	1.00	0.516	1.13
	-70	10955	0.94	537	0.88	0.419	1.03	0.492	1.14
	-80	16994	1.23	661	1.01	0.332	1.08	0.359	1.12
	-100	49153	1.35	816	1.09	0.027	0.64	0.033	0.63

*Corrected Strain Gage Data,
Class C Specimens

Table 6 concluded

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*
OF TP-H7070 PROPELLANT STORED IN BULK SEALED FORM
(Mix L-212)

Storage Time (months)	Test Temperature (°F)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
10	130	467	0.48	77	0.53	0.270	1.13	0.307	1.24
	77	600	0.55	89	0.50	0.252	0.93	0.287	0.98
	20	1137	0.75	117	0.53	0.235	0.88	0.297	1.03
	-30	4251	1.24	222	0.69	0.265	0.84	0.374	1.01
	-50	6889	1.18	296	0.72	0.295	0.84	0.424	1.09
12	160	299	0.34	58	0.44	0.282	1.17	0.320	1.29
	130	315	0.32	67	0.46	0.296	1.24	0.341	1.38
	77	448	0.41	82	0.46	0.280	1.04	0.335	1.15
	60	492	0.39	82	0.44	0.273	1.06	0.324	1.18
	40	758	0.53	118	0.59	0.271	1.04	0.338	1.19
	20	861	0.57	119	0.54	0.281	1.06	0.359	1.25
	0	1470	0.76	152	0.60	0.268	0.95	0.321	1.04
	-30	2804	0.82	188	0.59	0.262	0.84	0.353	0.96
	-50	5596	0.96	286	0.70	0.319	0.91	0.422	0.92
	-65	9494	0.91	408	0.72	0.405	0.99	0.511	1.12
	-70	12041	1.04	494	0.81	0.410	1.01	0.488	1.13
	-80	16304	1.18	628	0.96	0.327	1.06	0.352	1.10
	-100	36381	1.00	793	1.06	0.037	0.88	0.042	0.81

*Corrected Strain Gage Data,
Class C Specimens

TABLE 7

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*
OF TP-H7038 PROPELLANT STORED IN GRADIENT FORM (N_2 DESICCANT)

(Pressure Cast; Mix L-32)

Storage Time (mo)	Test Temperature (°F)	Depth (in)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	77		645		125		0.289		0.329	
3	77	Surface	704	1.09	137	1.10	0.307	1.06	0.337	1.02
		0.75	608	0.94	123	0.98	0.300	1.04	0.340	1.03
		1.25	614	0.95	120	0.96	0.293	1.01	0.324	0.98
		1.75	679	1.05	118	0.94	0.273	0.94	0.311	0.95
6	77	Surface	892	1.38	144	1.15	0.263	0.91	0.292	0.89
		0.75	611	0.95	103	0.82	0.277	0.96	0.320	0.97
		1.25	599	0.93	103	0.82	0.280	0.97	0.317	0.96
		1.75	752	1.17	113	0.90	0.253	0.88	0.289	0.88
12	77	Surface	885	1.37	159	1.27	0.289	1.00	0.308	0.94
		0.75	651	1.01	118	0.94	0.307	1.06	0.363	1.10
		1.25	593	0.92	109	0.87	0.302	1.04	0.366	1.11
		1.75	576	0.89	104	0.83	0.310	1.07	0.396	1.20

*Corrected Strain Gage Data,
Class C Specimens

TABLE 8

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*

OF TP-H7038 PROPELLANT STORED IN GRADIENT FORM (N_2)

(N-432)

Storage Time	Test Temperature	Depth	Modulus		Maximum Stress		Strain at Maximum Stress		Strain at Cracking	
(months)	(°F)	(in.)	(psi)	(E/E_o)	(psi)	(σ/σ_o)	(in/in)	(e/e_o)	(in/in)	(e/e_o)
0	77		1099		204		0.327		0.343	
3	77	Surface	751	0.68	157	0.77	0.330	1.01	0.353	1.03
		0.75	871	0.79	180	0.88	0.367	1.12	0.390	1.15
		1.25	833	0.76	174	0.85	0.343	1.05	0.365	1.06
		1.75	818	0.74	164	0.80	0.337	1.03	0.369	1.08
6	77	Surface	237	0.22	59	0.29	0.371	1.13	0.471	1.37
		0.75	409	0.37	94	0.46	0.351	1.07	0.411	1.20
		1.25	473	0.43	106	0.52	0.343	1.05	0.385	1.12
		1.75	554	0.50	117	0.57	0.353	1.08	0.407	1.19
9	77	Surface	142	0.13	24	0.12	0.493	1.51	0.594	1.73
		0.75	221	0.20	43	0.21	0.406	1.24	0.494	1.44
		1.25	335	0.30	62	0.30	0.350	1.07	0.439	1.28
		1.75	410	0.37	74	0.36	0.347	1.06	0.426	1.24
12	77	Surface	144	0.13	26	0.13	0.567	1.73	0.789	2.30
		0.75	203	0.18	42	0.21	0.430	1.31	0.569	1.66
		1.25	248	0.22	55	0.27	0.397	1.21	0.510	1.49
		1.75	312	0.28	59	0.29	0.373	1.14	0.455	1.33

*Corrected Strain Gage Data,
Class C Specimens

TABLE 9

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES* OF

TP-H7038 PROPELLANT STORED IN GRADIENT FORM (N_2 DESICCANT)

(N-433)

Storage Time (months)	Test Temperature (°F)	Depth (in.)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ / σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	77		1099		204		0.327		0.343	
3	77	Surface	1320	1.20	249	1.22	0.309	0.94	0.314	0.92
		0.75	1107	1.01	212	1.04	0.335	1.02	0.352	1.03
		1.25	1187	1.08	183	0.90	0.330	1.01	0.344	1.00
		1.75	859	0.78	167	0.82	0.293	0.90	0.299	0.87
6	77	Surface	1001	0.91	184	0.90	0.312	0.95	0.340	0.99
		0.75	757	0.69	150	0.74	0.358	1.09	0.397	1.16
		1.25	686	0.62	136	0.67	0.352	1.08	0.402	1.17
		1.75	700	0.64	134	0.66	0.334	1.02	0.362	1.06
9	77	Surface	973	0.89	184	0.90	0.248	0.76	0.254	0.74
		0.75	501	0.46	120	0.59	0.369	1.13	0.398	1.16
		1.25	523	0.48	114	0.56	0.357	1.09	0.401	1.17
		1.75	531	0.48	113	0.55	0.347	1.06	0.383	1.12
12	77	Surface	1258	1.13	197	0.97	0.232	0.71	0.237	0.69
		0.75	766	0.69	131	0.64	0.340	1.04	0.387	1.13
		1.25	602	0.54	117	0.57	0.347	1.06	0.392	1.14
		1.75	613	0.55	117	0.57	0.351	1.07	0.412	1.20

*Corrected Strain Gage Data,
Class C Specimens

TABLE 10

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES* OF TP-H7070 PROPELLANT STORED IN GRADIENT FORM (N_2 DESICCANT)

(Mix L-212)

Storage Time (mo.)	Test Temp. (°F)	Depth (in.)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	77		1093		179		0.270		0.292	
3	77	Surface	1044	0.96	145	0.81	0.251	0.93	0.267	0.91
		0.75	1051	0.96	144	0.80	0.251	0.93	0.266	0.91
		1.25	991	0.91	145	0.81	0.259	0.96	0.280	0.96
		1.75	986	0.90	144	0.80	0.255	0.94	0.278	0.95
		2.75	937	0.86	144	0.80	0.262	0.97	0.288	0.99
		3.75	934	0.85	143	0.80	0.259	0.96	0.274	0.94
		4.25	949	0.87	143	0.80	0.262	0.97	0.282	0.97
6	77	Surface	815	0.75	127	0.71	0.284	1.05	0.308	1.05
		0.75	763	0.70	121	0.68	0.282	1.04	0.305	1.04
		1.25	744	0.68	120	0.67	0.286	1.06	0.309	1.06
		1.75	757	0.69	119	0.66	0.276	1.02	0.298	1.02
		2.75	741	0.68	118	0.66	0.283	1.05	0.305	1.04
		3.75	760	0.70	117	0.65	0.268	0.99	0.280	0.96

*Corrected Strain Gage Data, Class C Specimens

TABLE 11

SAM-D PROPELLANT SUMMARY

Propellant		TP-H 7038	TP-H 7070	TP-H 8208	TP-H 7038	TP-H 7038	TP-H 7038
Mix(es)		Various	L-212	Various	Q14705	R1065	R1066
AP Ratio							
Special Coarse, %		45.0	45.0	0	0	0	0
Unground, %		27.5	27.5	70	80	80	80
Ground, %		27.5	27.5	30	20	20	20
I/E Ratio		5/1	3.8/1	N/A	5/1	5/1	5/1
P/CA Ratio		1/.83	1/1	1/.8	1/.81	1/.80	1/.83
EOM Viscosity, kp		13	8.6	4	80*	12.8	14.0
6-hr. Viscosity, kp		25	---	22	--	28	33
Parameter	°F						
Modulus, psi	130	400	973	415	877	659	1131
Strain @ MS, %	130	30	24	52	31	35	31
Max. Stress, psi	130	100	146	142	148	125	154
Modulus, psi	77	700	1093	641	958	855	1257
Strain @ MS, %	77	32	27	53	36	37	37
Max. Stress, psi	77	125	179	169	176	144	189
Modulus, psi	-30	4500	3423	5448	5600	4284	5643
Strain @ MS, %	-30	36	31	71	39	50	56
Max. Stress, psi	-30	300	319	481	385	346	447
Modulus, psi	-65	13000	10401	14615	15000	17827	15454
Strain @ MS, %	-65	36	41	45	43	52	48
Max. Stress, psi	-65	600	563	865	735	715	738
Strain Endurance, %		30%	22%	47%	30%	34%	22%
Burning Rate, in/sec		.434	.432	.434	No Test	No Test	.420

*Propellant Temperature = 120°F

TABLE 12

MODIFIED TP-H7038 PROPELLANT BALLISTICS
Mix W-24

Test Results

Charge	Test Temp., °F	K_n	Web Time, sec.	Avg. Pressure, psia	Burn Rate, in/sec.
1	-50	275	1.762	1024	0.352
2	130	271	1.496	1187	0.415
3	-50	321	1.651	1286	0.375
4	130	315	1.412	1499	0.439
5	40	344	1.497	1532	0.414
6	40	248	1.672	990	0.370
7	40	288	1.589	1226	0.390
8	40	289	1.586	1232	0.391

Calculated Ballistics, 70°F, P_{avg} Variable

Avg. Pressure, psia	K_n	Burn Rate, in/sec
1000	247	0.379
1100	263	.388
1200	279	.397
1300	295	.405
1400	312	.413
1450	320	.416
1500	328	.420
1600	345	.427
1700	362	.434

TABLE 13

BULK PHYSICAL PROPERTIES* OF MODIFIED TP-H7038 PROPELLANT
(Mix W-24)

Test Temp. (°F)	Modulus (psi)	Maximum Stress (psi)	Strain at Max. Stress (in/in)	Strain at Cracking (in/in)
160	730	136	0.346	0.355
130	741	151	0.389	0.397
77	887	192	0.438	0.452
60	993	197	0.455	0.469
40	1108	219	0.467	0.480
20	1544	245	0.462	0.483
0	2437	294	0.478	0.502
-20	3486	369	0.522	0.546
-30	5320	422	0.508	0.539
-45	7741	543	0.521	0.543
-55	11306	659	0.568	0.594
-65	15794	754	0.502	0.517
-70	17313	791	0.464	0.472
-80	20530	828	0.166	0.193

*Corrected Strain Gage Data, Class C Specimens

TABLE 14

MODIFIED TP-H7038 PROPELLANT AGING PROGRAM
(Mix W-24)

Sample Type	Temperature, (°F) Storage	Test	Time (Months) 0	1	2	3	4	4.5	5	6	9	12	Spares
Bulk Sealed	Ambient	FB[1]	2[2]							2		2	5
	130	FB				2			2	2		2	
Bulk Gradient	Ambient												
	(N_2)[3]	77	1			1				1	1	1	
	$(N_2$, des)[4]	77				1				1	1	1	
	130												
	(N_2)	77	1	1		1		1		1	1	1	
	$(N_2$, des)	77				1		1		1	1	1	

1. FB - Failure Boundary: 14 temperatures, -80 to 160°F; strain endurance.
2. Two samples.
3. Nitrogen purged.
4. Nitrogen purged with desiccant (1-2g. Molecular Sieves).

TABLE 15

EFFECT OF AMBIENT TEMPERATURE STORAGE ON THE PHYSICAL PROPERTIES* OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK SEALED FORM

(Mix W-24)

Storage Time (months)	Test Temp. (°F)	Modulus (psi)	Maximum Stress (psi)	Strain at Max. Stress (in/in)	Strain at Cracking (in/in)
0	160	730	136	0.346	0.355
	130	741	151	0.389	0.397
	77	887	192	0.438	0.452
	60	993	197	0.455	0.469
	40	1108	219	0.467	0.480
	20	1544	245	0.462	0.483
	0	2437	294	0.478	0.502
	-20	3486	369	0.522	0.546
	-30	5320	422	0.508	0.539
	-45	7741	543	0.521	0.543
	-55	11306	659	0.568	0.594
	-65	15794	754	0.502	0.517
	-70	17313	791	0.464	0.472
	-80	20530	828	0.166	0.193
6	160	951	142	0.329	0.336
	130	909	136	0.286	0.293
	77	1155	189	0.383	0.396
	60	1149	190	0.425	0.436
	40	1375	227	0.427	0.438
	20	1595	239	0.448	0.468
	0	2889	306	0.439	0.453
	-20	3687	343	0.454	0.477
	-30	4752	439	0.506	0.535
	-45	8527	484	0.483	0.513
	-55	11115	686	0.575	0.588
	-65	14277	694	0.443	0.478
	-70	17325	829	0.454	0.465
	-80	21802	788	0.059	0.174

*Corrected Strain Gage Data, Class C Specimens

TABLE 16

EFFECT OF 1[illegible]0°F STORAGE ON THE PHYSICAL PROPERTIES* OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK SEALED FORM

(Mix W-24)

Storage Time (months)	Test Temp. (°F)	Modulus (psi)	Maximum Stress (psi)	Strain at Max. Stress (in/in)	Strain at Cracking (in/in)
0	160	730	136	0.346	0.355
	130	741	151	0.389	0.397
	77	887	192	0.438	0.452
	60	993	197	0.455	0.469
	40	1108	219	0.467	0.480
	20	1544	245	0.462	0.483
	0	2437	294	0.478	0.502
	-20	3486	369	0.522	0.546
	-30	5320	422	0.508	0.539
	-45	7741	543	0.521	0.543
	-55	11306	659	0.568	0.594
	-65	15794	754	0.502	0.517
	-70	17313	791	0.464	0.472
	-80	20530	828	0.166	0.193
3	160	640	127	0.373	0.382
	130	694	131	0.378	0.384
	77	951	171	0.460	0.472
	60	1088	179	0.447	0.461
	40	1174	1[illegible]8	0.455	0.466
	20	2323	227	0.459	0.477
	0	28[illegible]3	281	0.511	0.543
	-20	4527	344	0.498	0.532
	-30	6488	382	0.523	0.548
	-45	10106	514	0.536	0.563
	-55	12620	592	0.508	0.528
	-65	18135	715	0.497	0.502
	-70	18629	759	0.395	0.410
	-80	22902	854	0.106	0.149

*Corrected Strain Gage Data, Class C Specimens

TABLE 16 (concluded)

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES* OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK SEALED FORM
(Mix W-24)

Storage Time (months)	Test Temp. (°F)	Modulus (psi)	Maximum Stress (psi)	Strain at Max. Stress (in/in)	Strain at Cracking (in/in)
5	160	623	115	0.379	0.389
	130	600	117	0.404	0.414
	77	950	159	0.415	0.426
	60	951	163	0.469	0.485
	40	1379	196	0.457	0.474
	20	1712	213	0.514	0.536
	0	2711	267	0.461	0.479
	-20	4120	330	0.491	0.523
	-30	5592	384	0.472	0.495
	-45	7763	497	0.613	0.648
	-55	11885	612	0.474	0.494
	-65	14224	727	0.472	0.485
	-70	18013	798	0.351	0.365
	-80	17656	681	0.068	0.139
6	160	508	121	0.430	0.440
	130	718	111	0.373	0.382
	77	922	159	0.433	0.446
	60	920	148	0.440	0.459
	40	1237	184	0.431	0.441
	20	1845	202	0.470	0.493
	0	2577	270	0.485	0.511
	-20	4466	312	0.493	0.533
	-30	4910	380	0.498	0.540
	-45	7074	463	0.588	0.680
	-55	11908	651	0.534	0.550
	-65	15250	752	0.550	0.580
	-70	18001	857	0.440	0.453
	-80	20899	848	0.073	0.144

*Corrected Strain Gage Data, Class C Specimens

TABLE 17

EFFECT OF AMBIENT TEMPERATURE STORAGE ON THE PHYSICAL PROPERTIES*
OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK GRADIENT FORM (N_2)
(Mix W-24)

Storage Time (months)	Test Temp. (°F)	Depth (in.)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	77		1027		185		0.445		0.461	
3	77	Surface	943	0.92	177	0.96	0.378	0.85	0.386	0.84
		0.75	1077	1.05	180	0.97	0.311	0.70	0.318	0.69
		1.75	1005	0.98	185	1.00	0.367	0.82	0.375	0.81
		2.75	1047	1.02	182	0.98	0.367	0.82	0.376	0.82
		3.75	1036	1.01	186	1.01	0.410	0.92	0.421	0.91
		4.75	1007	0.98	188	1.02	0.414	0.93	0.426	0.92
6	77	Surface	787	0.77	167	0.90	0.385	0.87	0.392	0.85
		0.75	841	0.82	179	0.97	0.392	0.88	0.400	0.87
		1.75	908	0.88	193	1.04	0.418	0.94	0.429	0.93
		2.75	961	0.94	192	1.04	0.405	0.91	0.423	0.92
		3.75	1013	0.99	192	1.04	0.417	0.94	0.431	0.93
		4.25	1062	1.03	187	1.01	0.366	0.82	0.374	0.81

*Corrected Strain Gage Data,
Class C Specimens

TABLE 18

EFFECT OF AMBIENT TEMPERATURE STORAGE ON THE PHYSICAL PROPERTIES* OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK GRADIENT FORM (N_2/Des.)
(Mix W-24)

Storage Time (months)	Test Temp. (^oF)	Depth (in.)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	77		1027		185		0.445		0.461	
3	77	Surface	1114	1.08	195	1.05	0.420	0.94	0.434	0.94
		0.75	1196	1.16	181	0.98	0.367	0.82	0.376	0.82
		1.75	1244	1.21	182	0.98	0.370	0.83	0.379	0.82
		2.75	1053	1.03	188	1.02	0.406	0.91	0.414	0.90
		3.75	1219	1.19	189	1.02	0.420	0.94	0.436	0.95
		4.25	1103	1.07	191	1.03	0.435	0.98	0.453	0.98
6	77	Surface	1091	1.06	169	0.91	0.340	0.76	0.349	0.76
		0.75	1094	1.07	166	0.90	0.316	0.71	0.325	0.70
		1.75	979	0.95	162	0.88	0.296	0.67	0.299	0.65
		2.75	1012	0.99	180	0.97	0.389	0.87	0.399	0.87
		3.75	1068	1.04	175	0.95	0.344	0.77	0.351	0.76
		4.25	971	0.95	168	0.91	0.327	0.73	0.337	[illegible]

*Corrected Strain Gage Data,
Class C Specimens

TABLE 19

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*
OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK GRADIENT FORM (N_2)

(Mix W-24)

Storage Time (months)	Test Temp. (°F)	Depth (in.)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	77		1027		185		0.445		0.461	
1	77	Surface	896	0.87	152	0.82	0.377	0.85	0.387	0.84
		0.75	990	0.96	174	0.94	0.373	0.84	0.380	0.82
		1.75	1099	1.07	182	0.98	0.364	0.82	0.370	0.80
		2.75	1096	1.07	184	0.99	0.381	0.86	0.390	0.85
		3.75	1142	1.11	184	0.99	0.377	0.85	0.385	0.94
		4.75	1185	1.15	185	1.00	0.370	0.83	0.380	0.82
2	77	Surface	605	0.59	130	0.70	0.423	0.95	0.437	0.95
		0.75	859	0.84	177	0.96	0.430	0.97	0.445	0.97
		1.75	888	0.86	177	0.96	0.411	0.92	0.421	0.91
		2.75	854	0.83	184	0.99	0.443	1.00	0.454	0.98
		3.75	979	0.95	182	0.98	0.414	0.93	0.423	0.92
		4.75	1073	1.04	179	0.97	0.385	0.87	0.396	0.86
3	77	Surface	500	0.49	104	0.56	0.385	0.87	0.404	0.88
		0.75	835	0.81	147	0.79	0.352	0.79	0.363	0.79
		1.75	867	0.85	175	0.95	0.438	0.98	0.449	0.97
		2.75	939	0.91	178	0.96	0.472	1.06	0.489	1.06
		3.75	942	0.92	177	0.96	0.466	1.05	0.479	1.04
		4.25	965	0.94	177	0.96	0.464	1.04	0.481	1.04

*Corrected Strain Gage Data,
Class C Specimens

TABLE 19 (concluded)

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*
OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK GRADIENT FORM (N_2)

Storage Time (months)	Test Temp. (°F)	Depth (in.)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
4.5	77	Surface	628	0.61	95	0.51	0.353	0.79	0.369	0.80
		0.75	824	0.80	146	0.79	0.428	0.96	0.446	0.97
		1.75	1005	0.98	169	0.91	0.398	0.89	0.406	0.88
		2.75	1043	1.02	168	0.91	0.382	0.86	0.390	0.85
		3.75	1131	1.10	173	0.94	0.448	1.01	0.463	1.00
		4.75	1051	1.02	170	0.92	0.399	0.90	0.410	0.89
6	77	Surface	366	0.36	65	0.35	0.326	0.73	0.396	0.86
		0.75	528	0.51	94	0.51	0.364	0.82	0.387	0.84
		1.75	814	0.79	141	0.76	0.388	0.87	0.402	0.87
		2.75	809	0.79	157	0.85	0.451	1.01	0.460	1.00
		3.75	807	0.79	158	0.85	0.458	1.03	0.472	1.02
		4.25	948	0.92	155	0.84	0.420	0.94	0.430	0.93

*Corrected Strain Gage Data,
Class C Specimens

TABLE 20

EFFECT OF 130°F STORAGE ON THE PHYSICAL PROPERTIES*
OF MODIFIED TP-H7038 PROPELLANT STORED IN BULK GRADIENT FORM (N_2/Des.)
(Mix W-24)

Storage Time (months)	Test Temp. (°F)	Depth (in.)	Modulus (psi)	Modulus (E/E_o)	Maximum Stress (psi)	Maximum Stress (σ/σ_o)	Strain at Maximum Stress (in/in)	Strain at Maximum Stress (e/e_o)	Strain at Cracking (in/in)	Strain at Cracking (e/e_o)
0	77		1027		185		0.445		0.461	
3	77	Surface	1036	1.01	169	0.91	0.358	0.80	0.367	0.80
		0.75	946	0.92	172	0.93	0.396	0.89	0.406	0.88
		1.75	842	0.82	163	0.88	0.381	0.86	0.394	0.85
		2.75	915	0.89	165	0.89	0.393	0.88	0.408	0.88
		3.75	945	0.92	165	0.89	0.403	0.91	0.416	0.90
		4.25	1067	1.04	167	0.90	0.391	0.88	0.408	0.88
4.5	77	Surface	1035	1.01	181	0.98	0.429	0.96	0.440	0.95
		0.75	1013	0.99	175	0.95	0.425	0.96	0.436	0.95
		1.75	1022	1.00	169	0.91	0.427	0.96	0.437	0.95
		2.75	999	0.97	164	0.89	0.372	0.84	0.382	0.83
		3.75	982	0.96	163	0.88	0.367	0.82	0.376	0.82
		4.75	1100	1.07	167	0.90	0.388	0.87	0.399	0.87
6	77	Surface	1007	0.98	167	0.90	0.452	1.02	0.464	1.01
		0.75	924	0.90	160	0.86	0.453	1.02	0.463	1.00
		1.75	875	0.85	152	0.82	0.408	0.92	0.416	0.90
		2.75	765	0.74	160	0.86	0.493	1.11	0.505	1.10
		3.75	812	0.79	159	0.86	0.525	1.18	0.553	1.20
		4.25	880	0.86	157	0.85	0.493	1.11	0.513	1.11

*Corrected Strain Gage Data, Class C Specimens

TABLE 21

RANKING OF CTPB BACK-UP PROPELLANTS AFTER AGING
(6 Months Storage at 130°F)

Bulk Storage

1.* Mix W-24 (TP-H7038, modified) (Figure 43)
2. Mix L-32 (TP-H7038, regular) (Figure 34)
3. Mix L-212 (TP-H7070) (Figure 32)
4. Mix N-432 (TP-H7038, regular) (Figure 33)

Gradient (N_2, without desiccant)
Surface Slab versus Time**

1. Mix W-24 (Figure 58)
2. Mix N-432 (Figure 35)

Gradient (N_2, with desiccant)
Surface Slab versus Time**

1. Mixes W-24, N-432 (Figures 62, 37)

Gradient (N_2, without desiccant)
Properties versus Depth

1. Mix W-24 (Figure 57)
2. Mix N-432 (Figure 63)

Gradient (N_2, with desiccant)
Properties versus Depth

1. Mixes W-24, L-32 (Figures 61, 64)
2. Mixes L-212, N-432 (Figures 39, 65)

*Ranking, best (1) to poorest (4).

**0 time through 6 months.

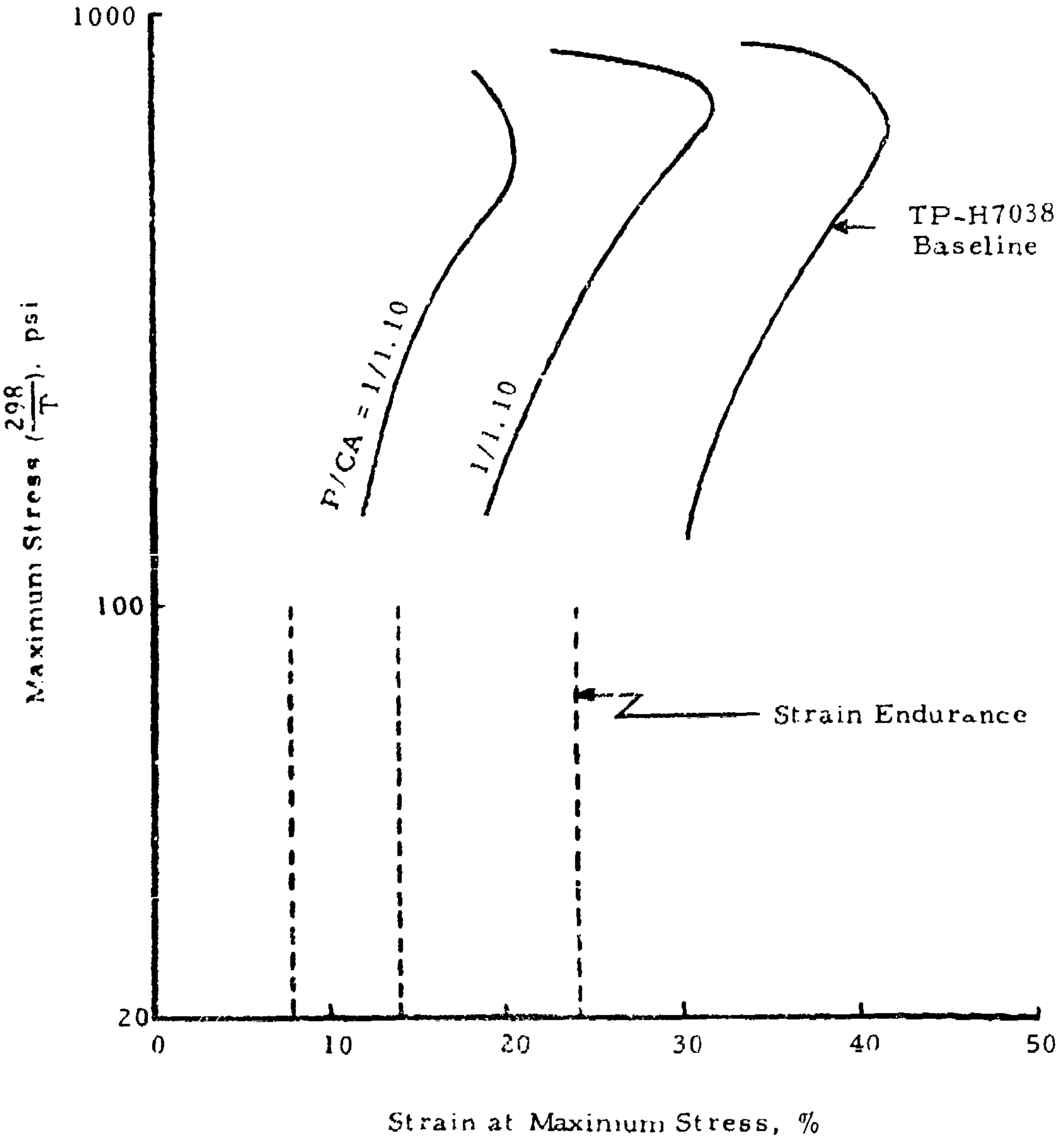


Figure 1. Effects of 2% DOA on Failure Chara cristics of TP-H7038 Propellant

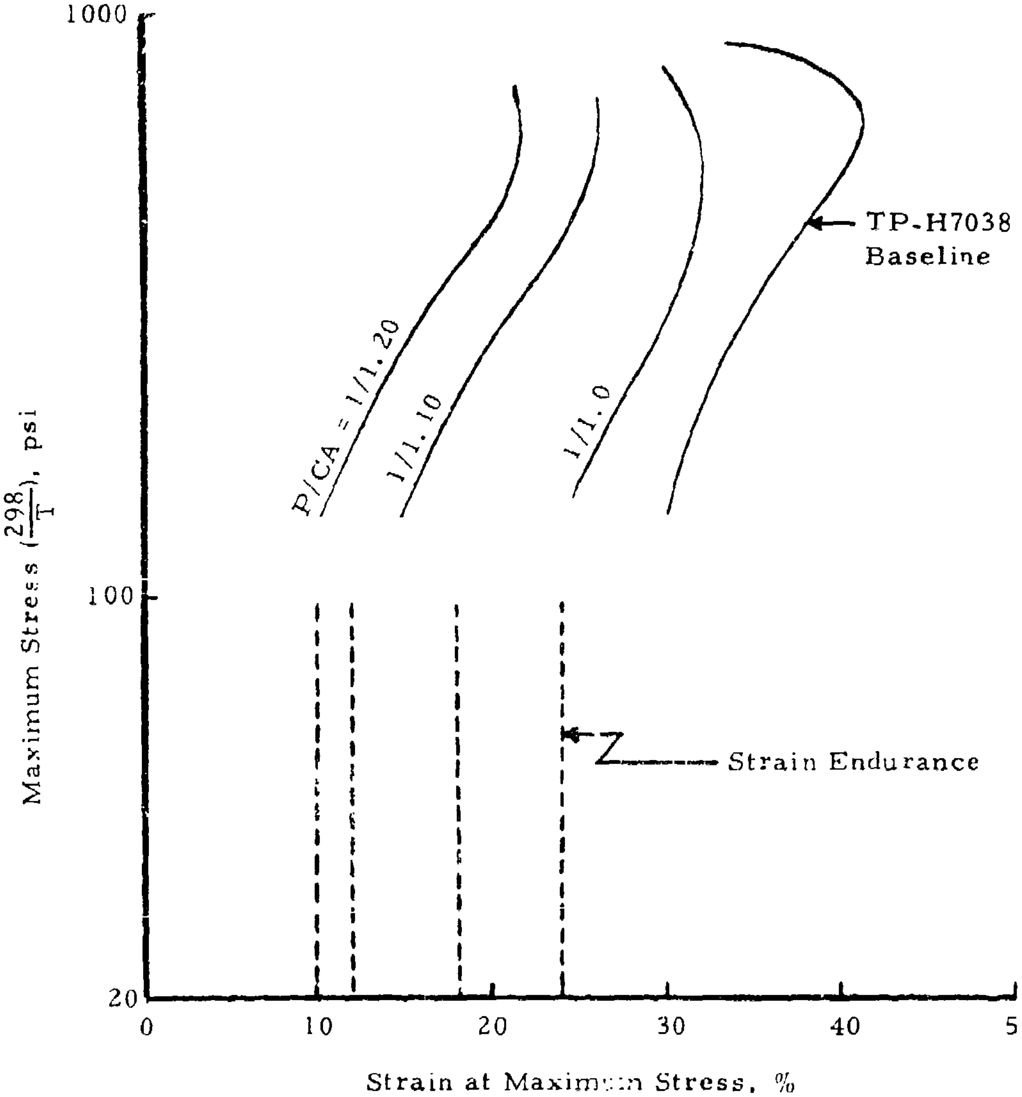


Figure 2. Effects of 3% DOA on Failure Characteristics of TP-H7038 Propellant

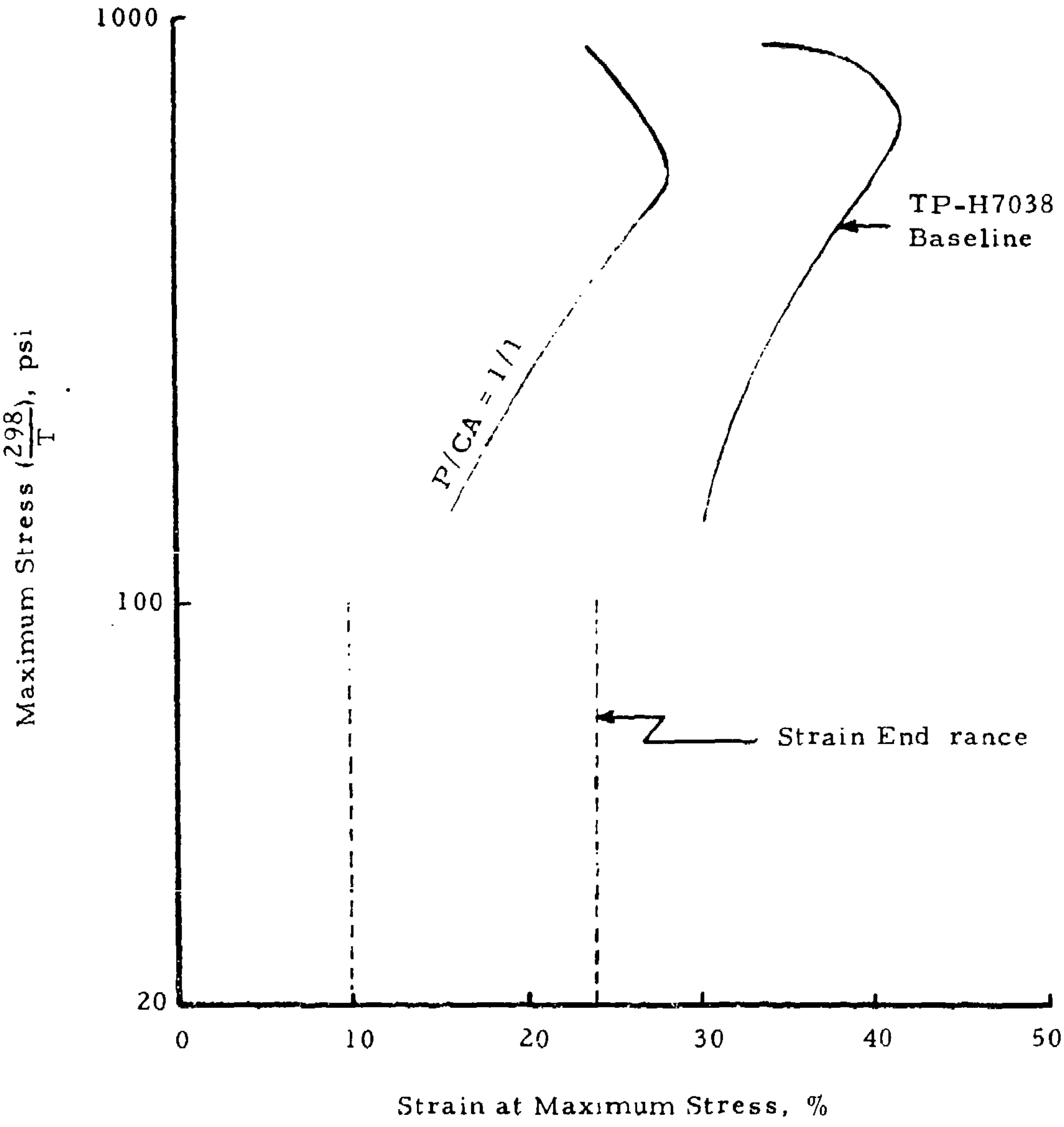


Figure 3. Effects of 1% TP-90B on the failure Characteristics of TP-H7038 Propellant

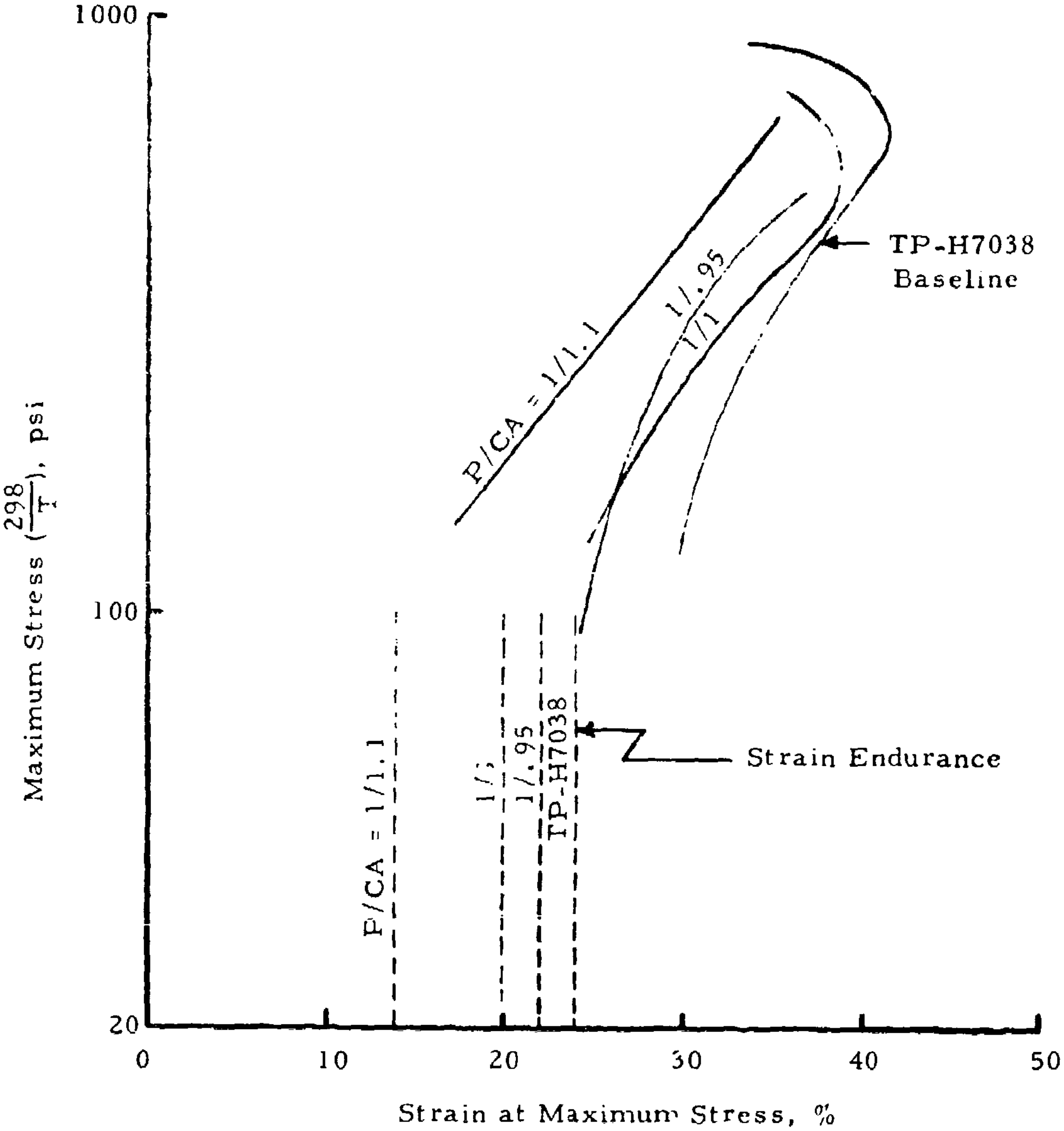


Figure 4. Effects of 2% TP-90B on the Failure Characteristics of TP-H7038 Propellant

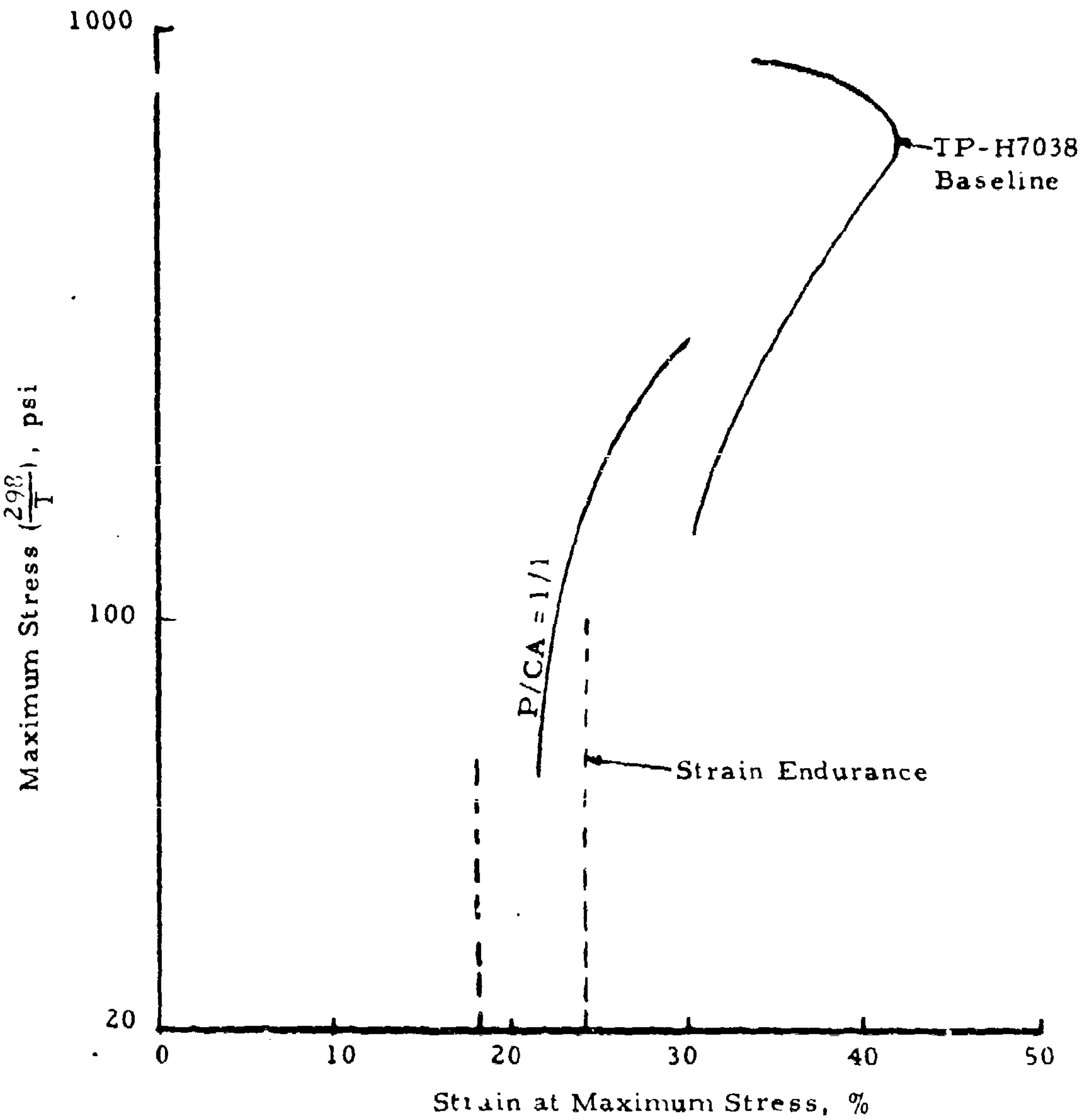


Figure 5. Effect of 3% TP-90B on the Failure Characteristics of TP-H7038 Propellant

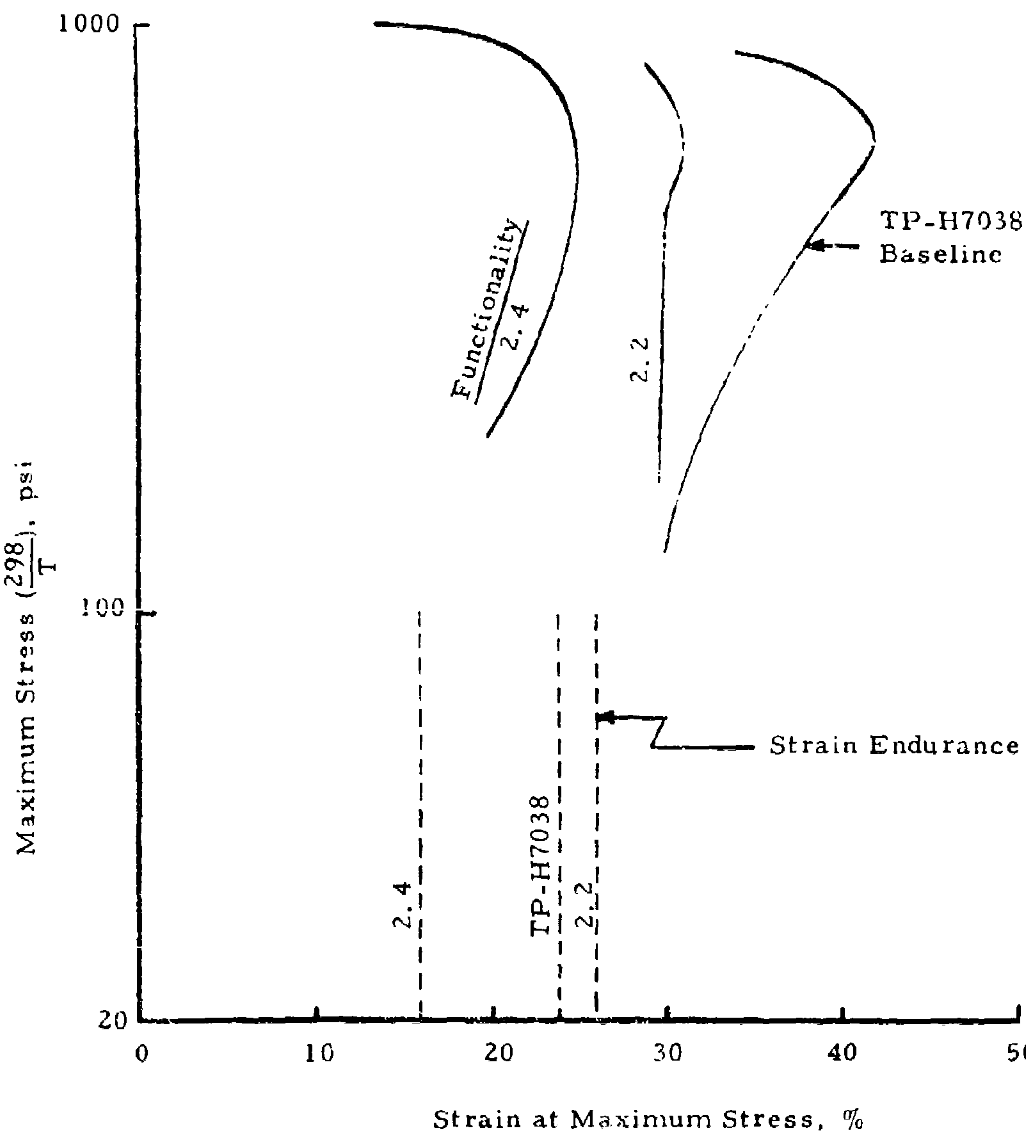


Figure 6. Effects of Imine Functionality on the Failure Characteristics of TP-H7038 Propellant

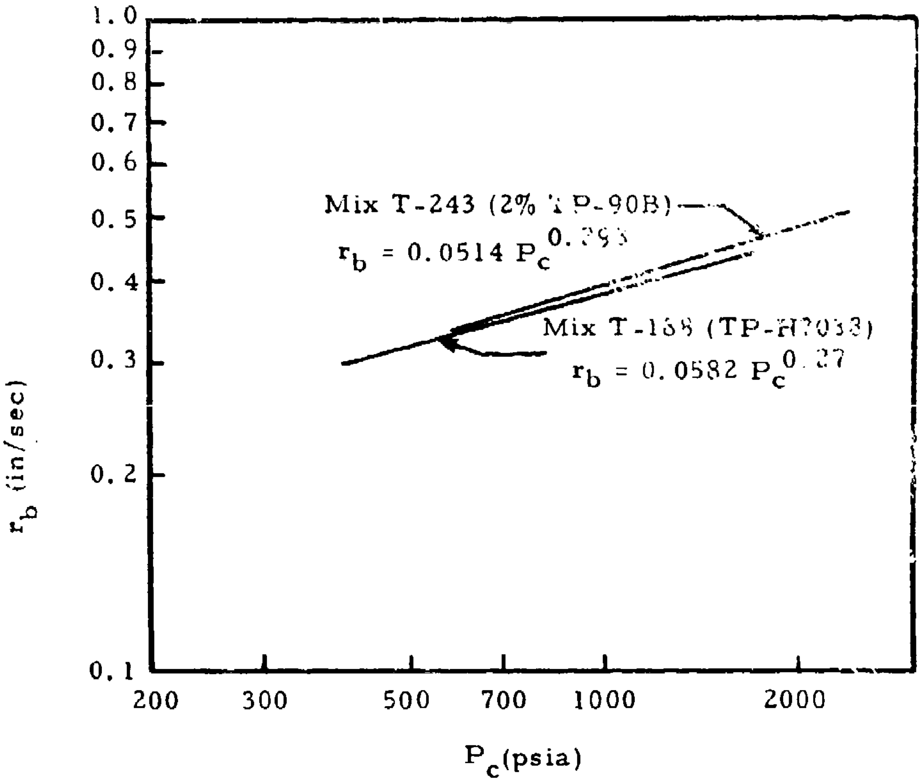


Figure 7. Effect of 2% TP-90B on Burning Rate of TP-H7038 Propellant

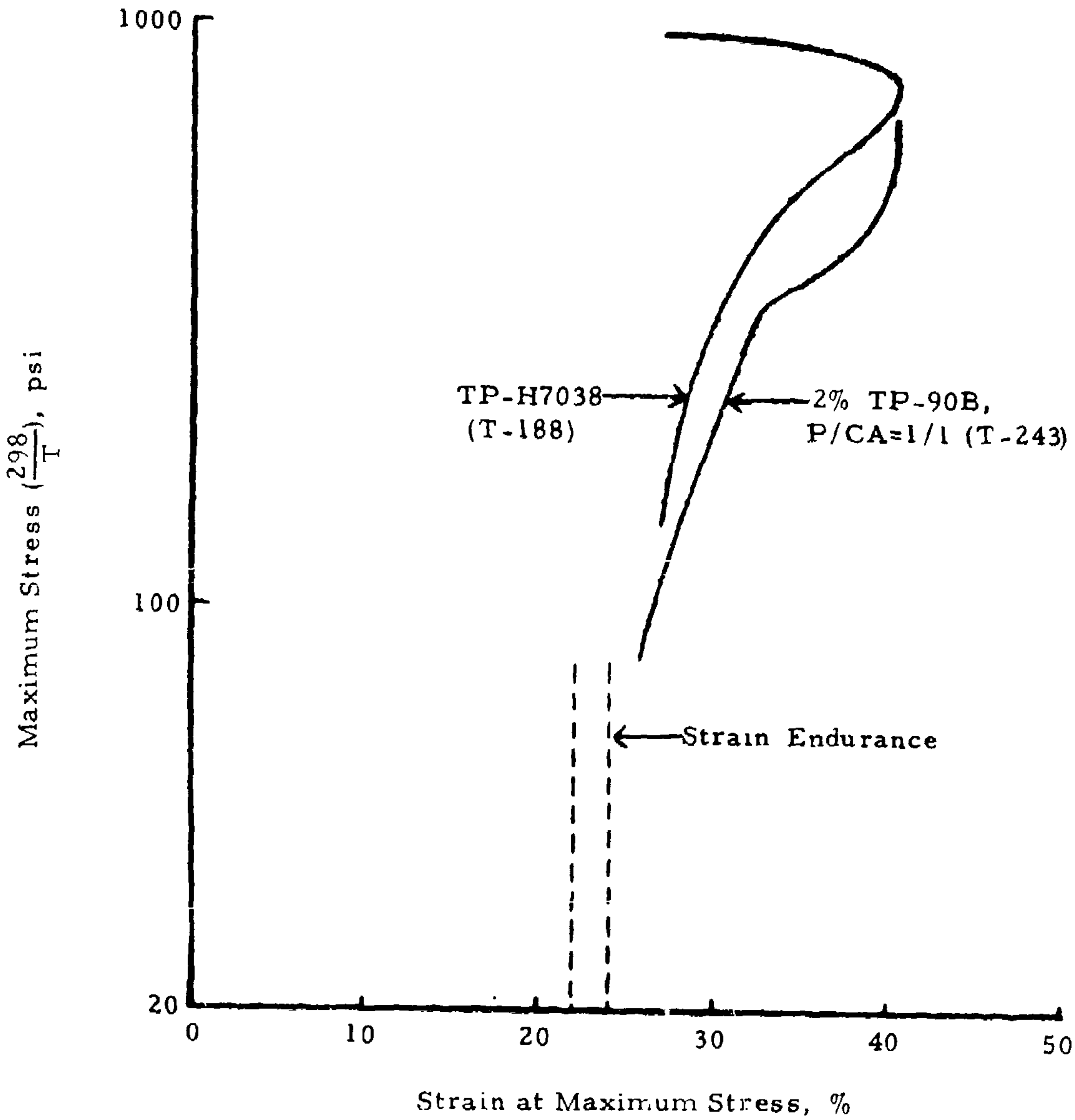


Figure 8. Effects of 2% TP-90B on Failure Boundary of TP-H7038 Propellant

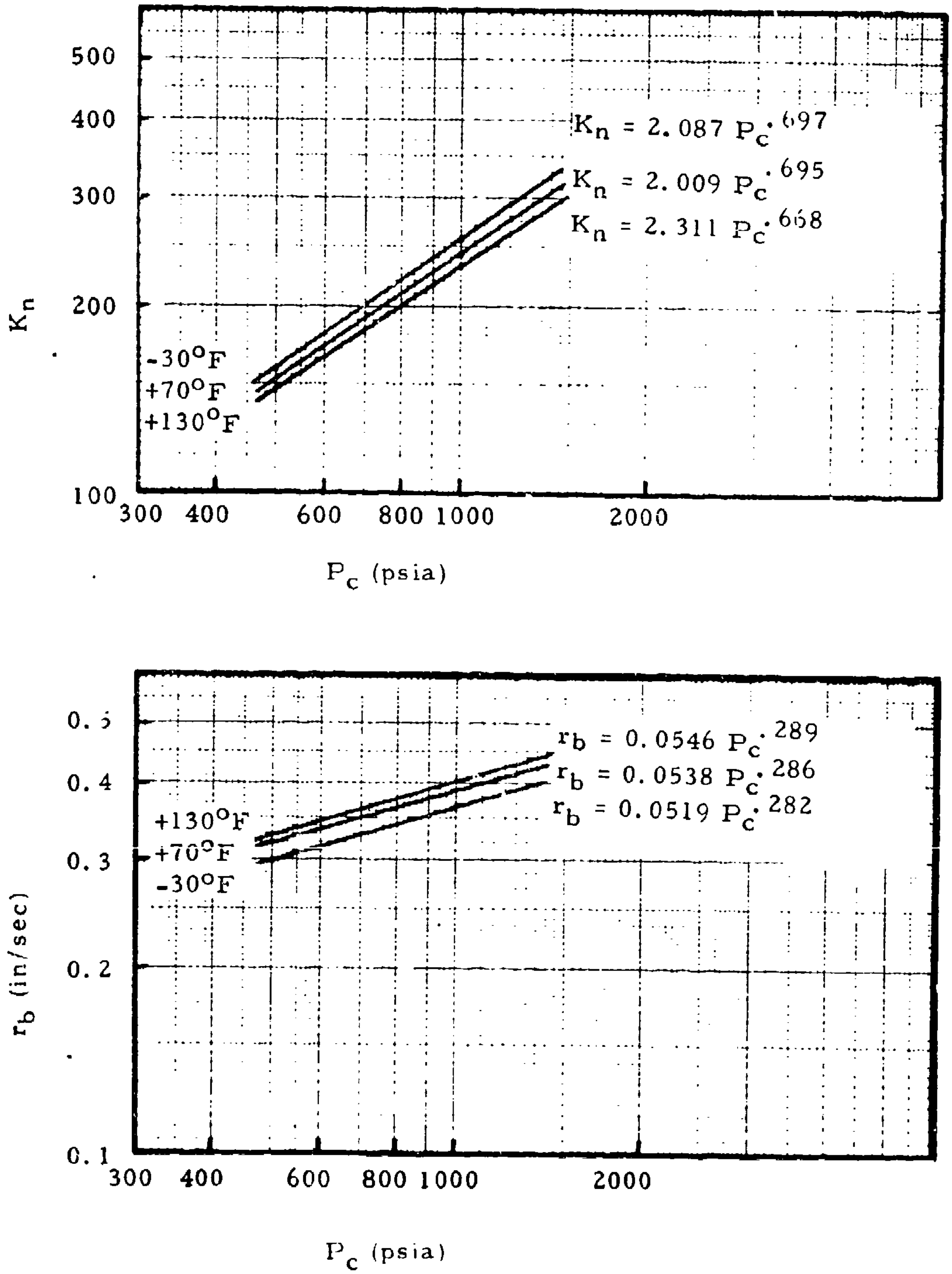


Figure 9. Burning Rate and K_n versus P_c for TP-H7070 Propellant, Mix L-212.

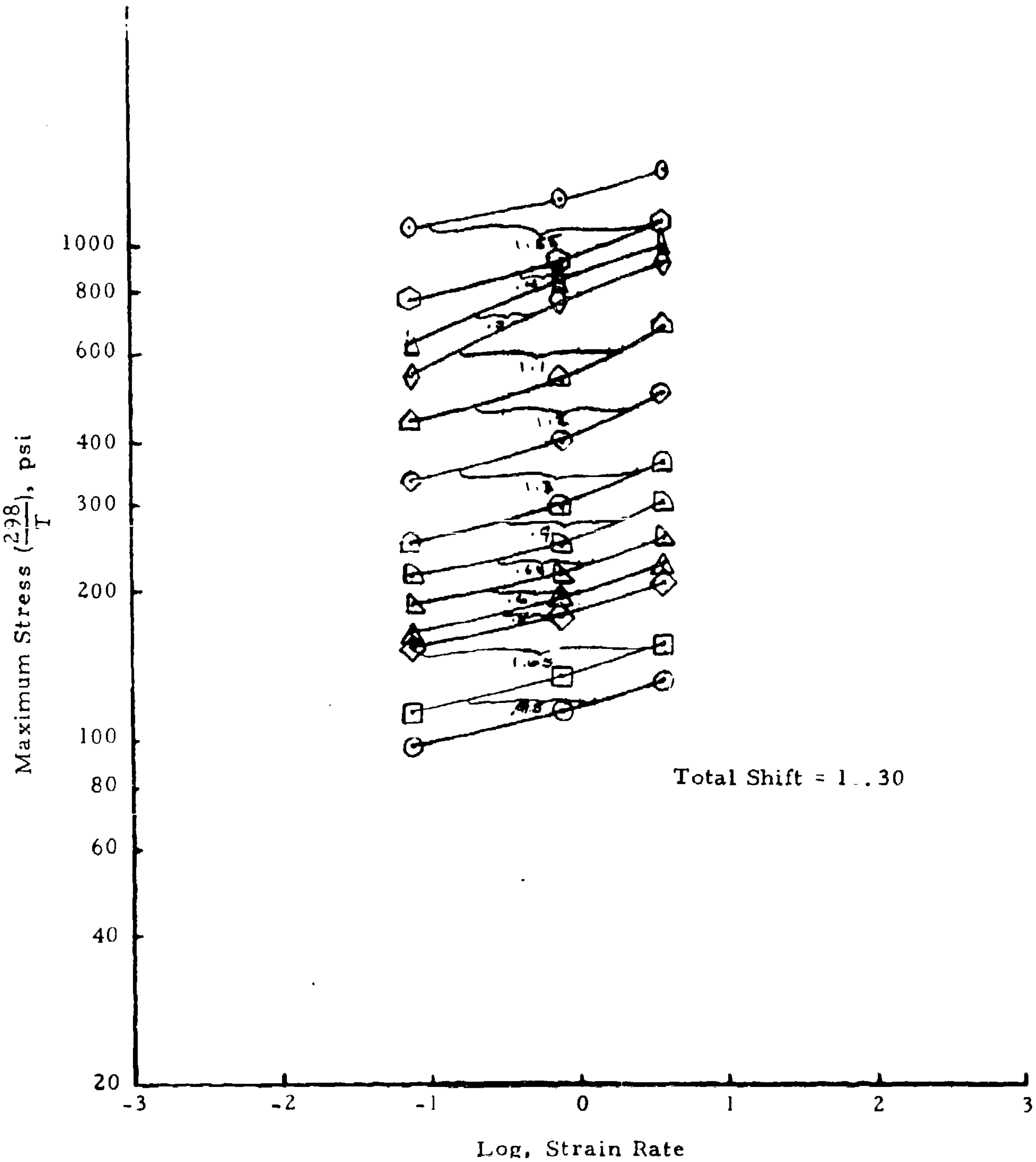


Figure 10. Determination of Time-Temperature Shift Factor, TP-H7070 Propellant, Mix L-212

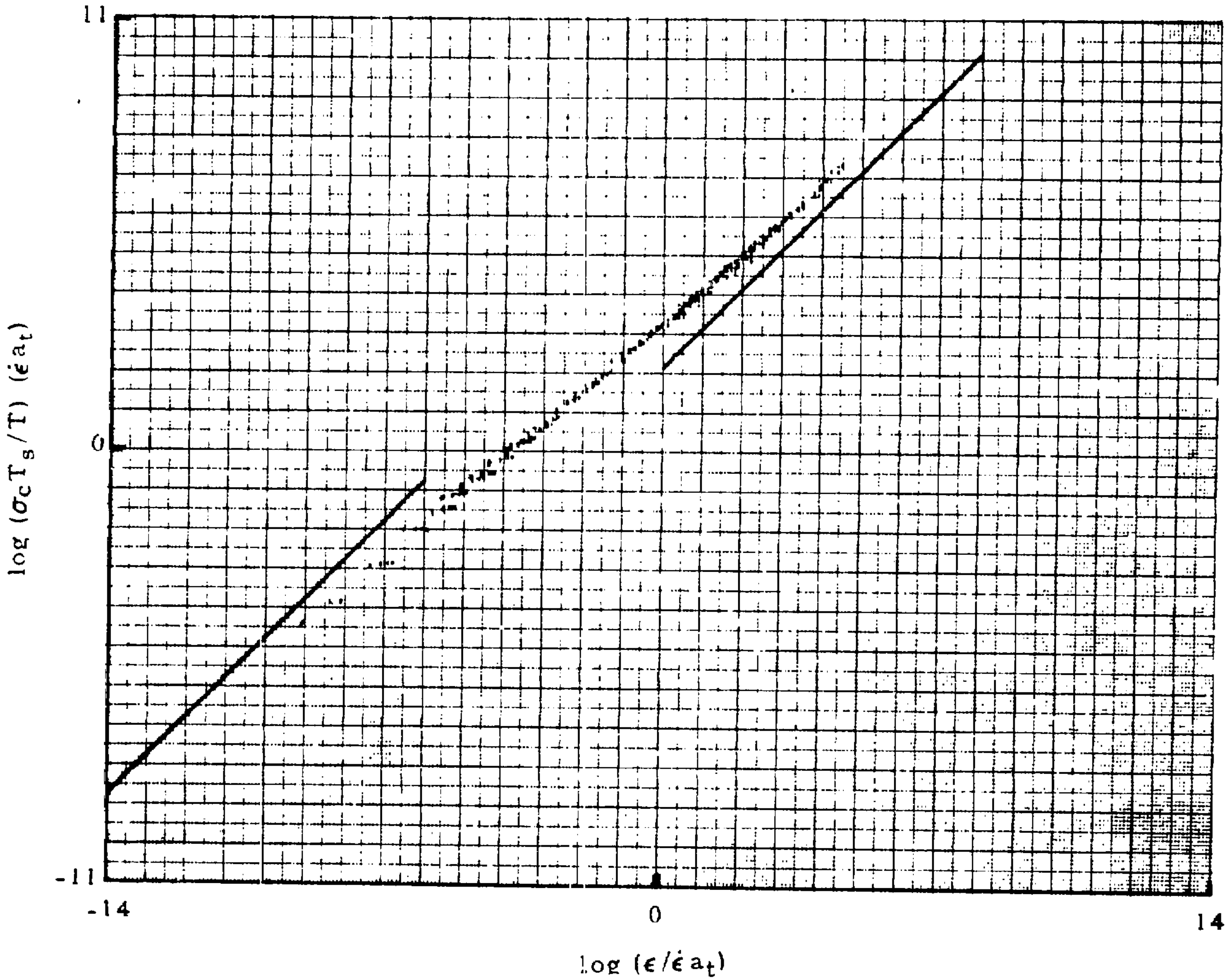


Figure 11. **Master Stress-Strain Curve TP-H7070 Propellant, Mix L-212**

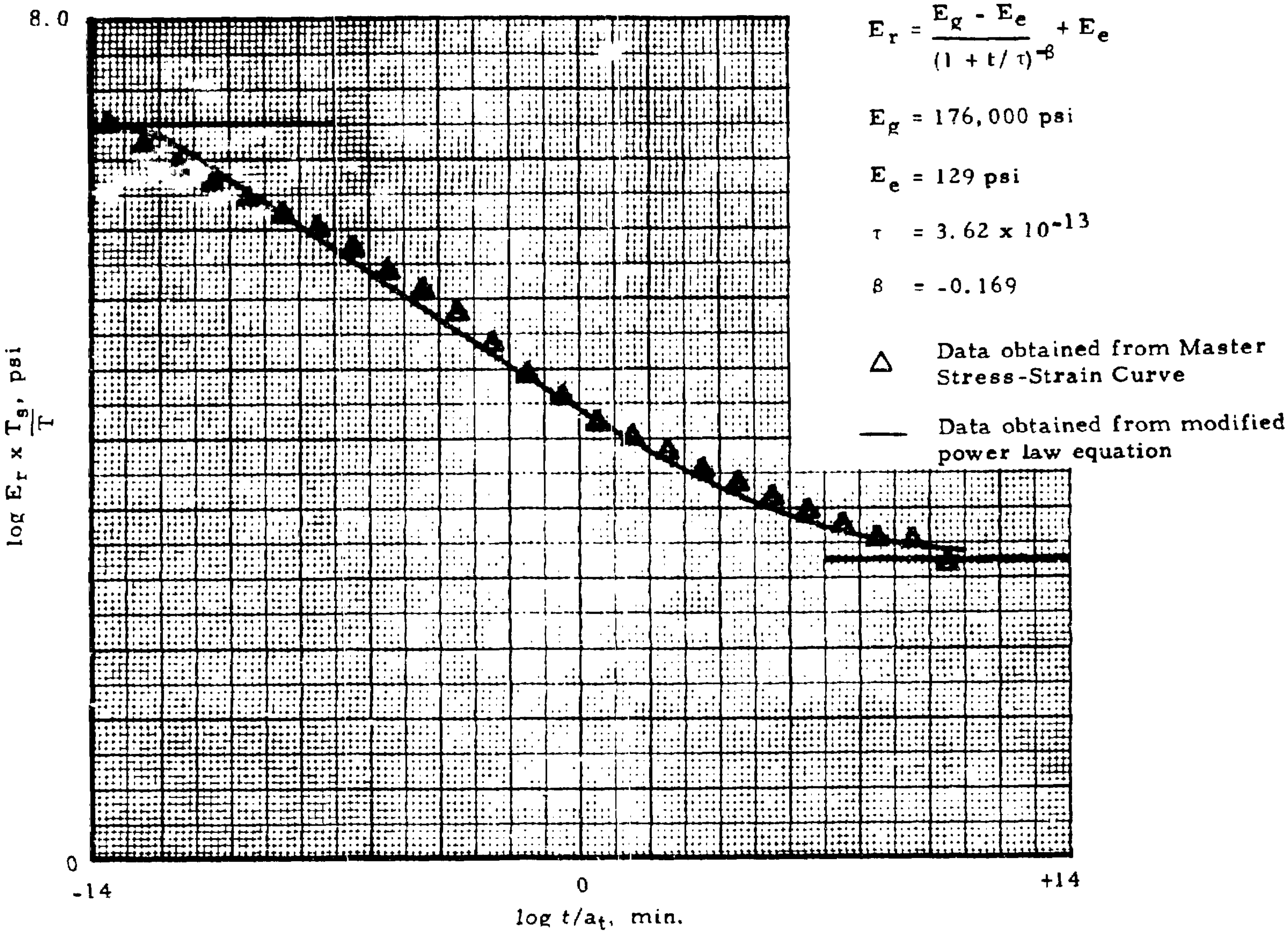


Figure 12. Relaxation Modulus, TP-H7070 Propellant, Mix L-212

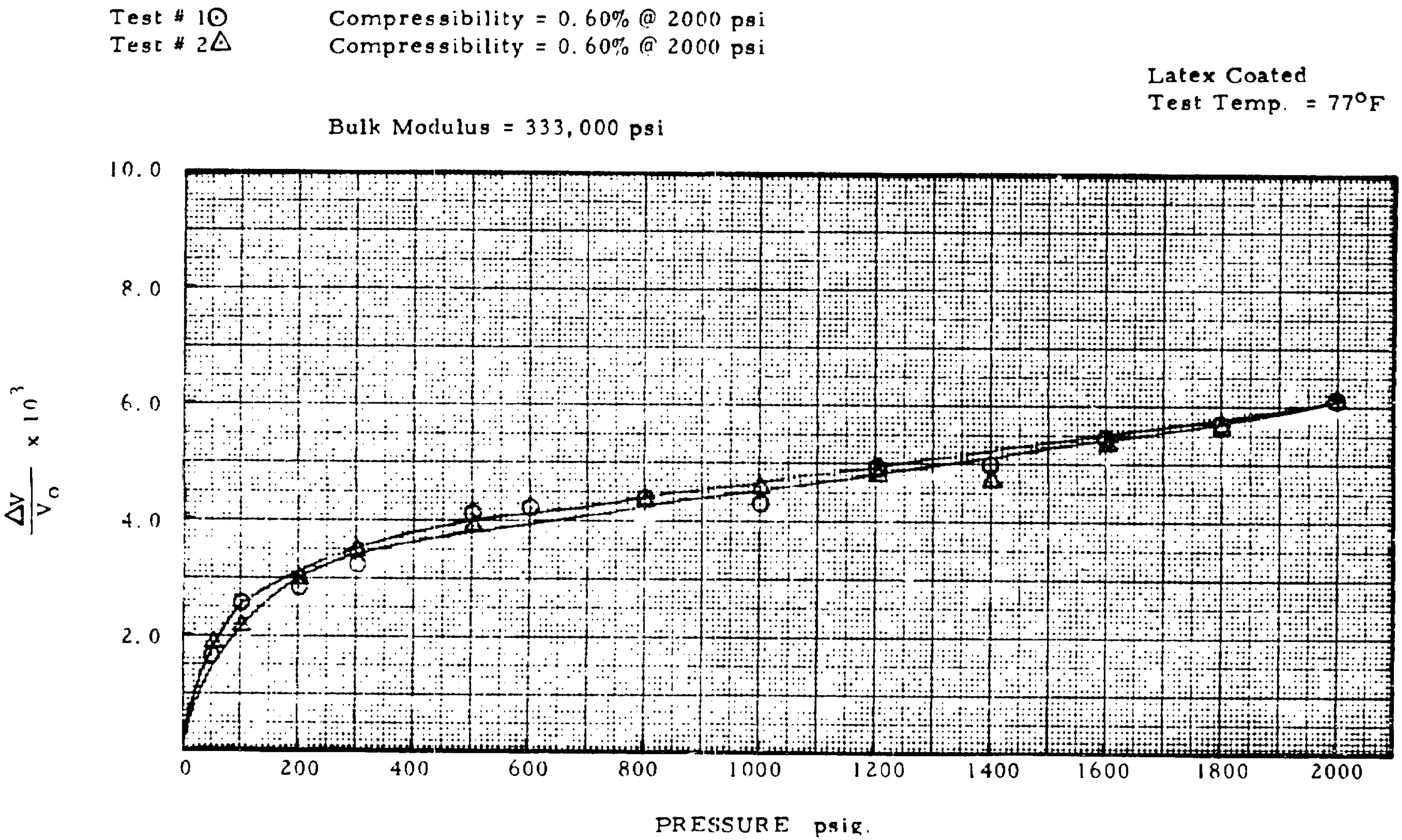


Figure 13. Hydrostatic Compressibility of TP-H7070 Propellant as a Function of Pressure.

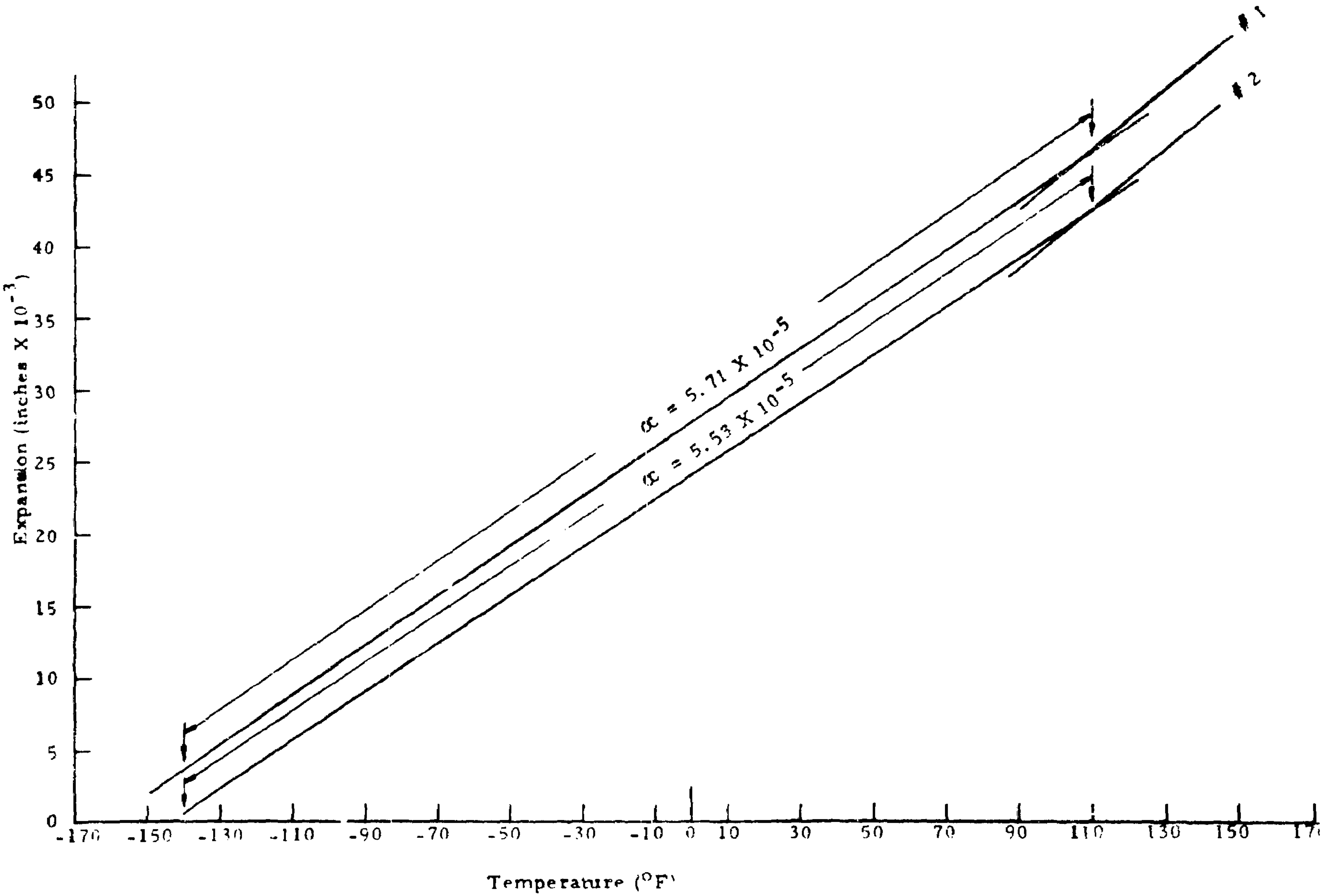
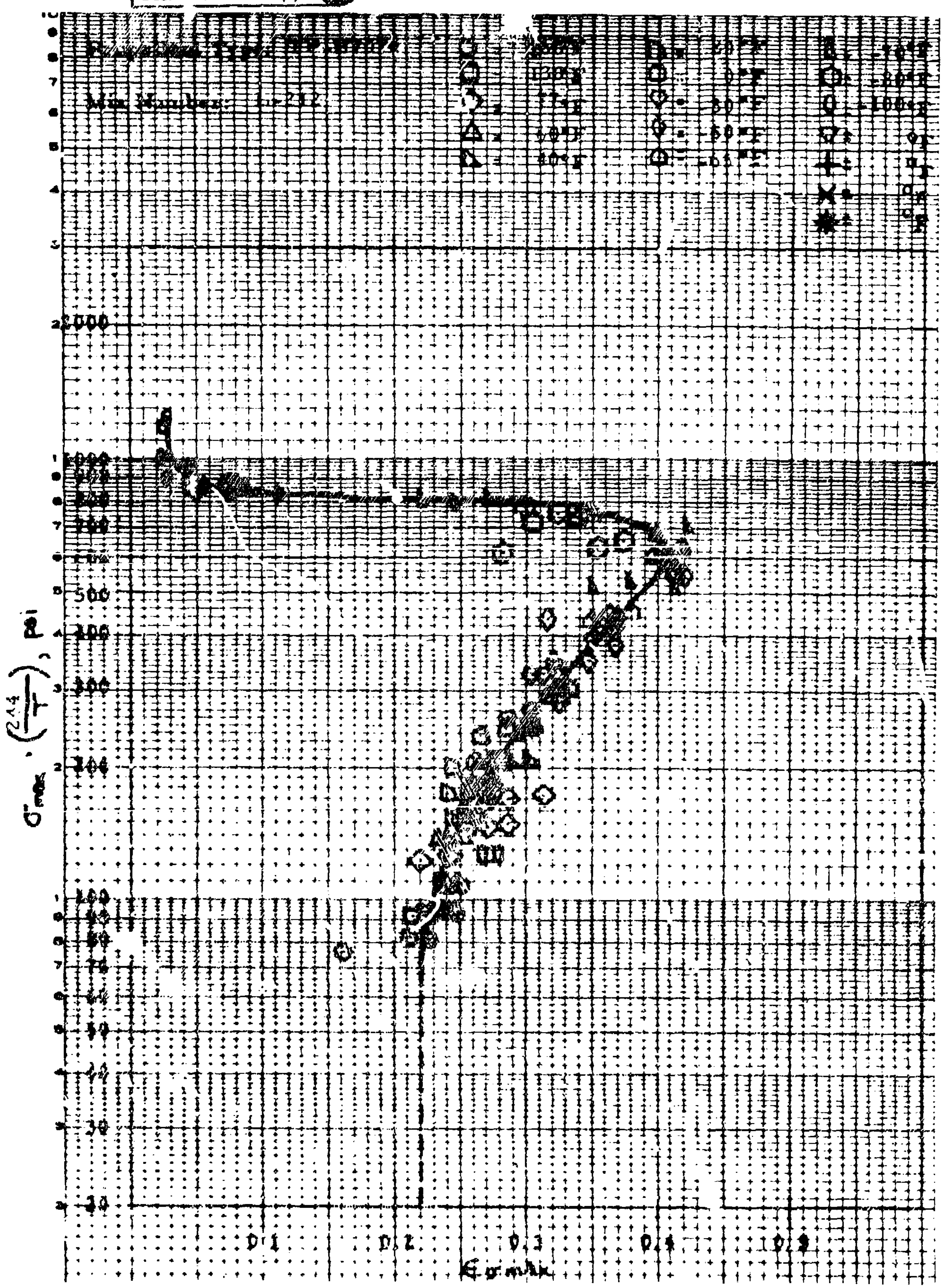


Figure 14. Thermal Expansion of TP-H7070 Propellant



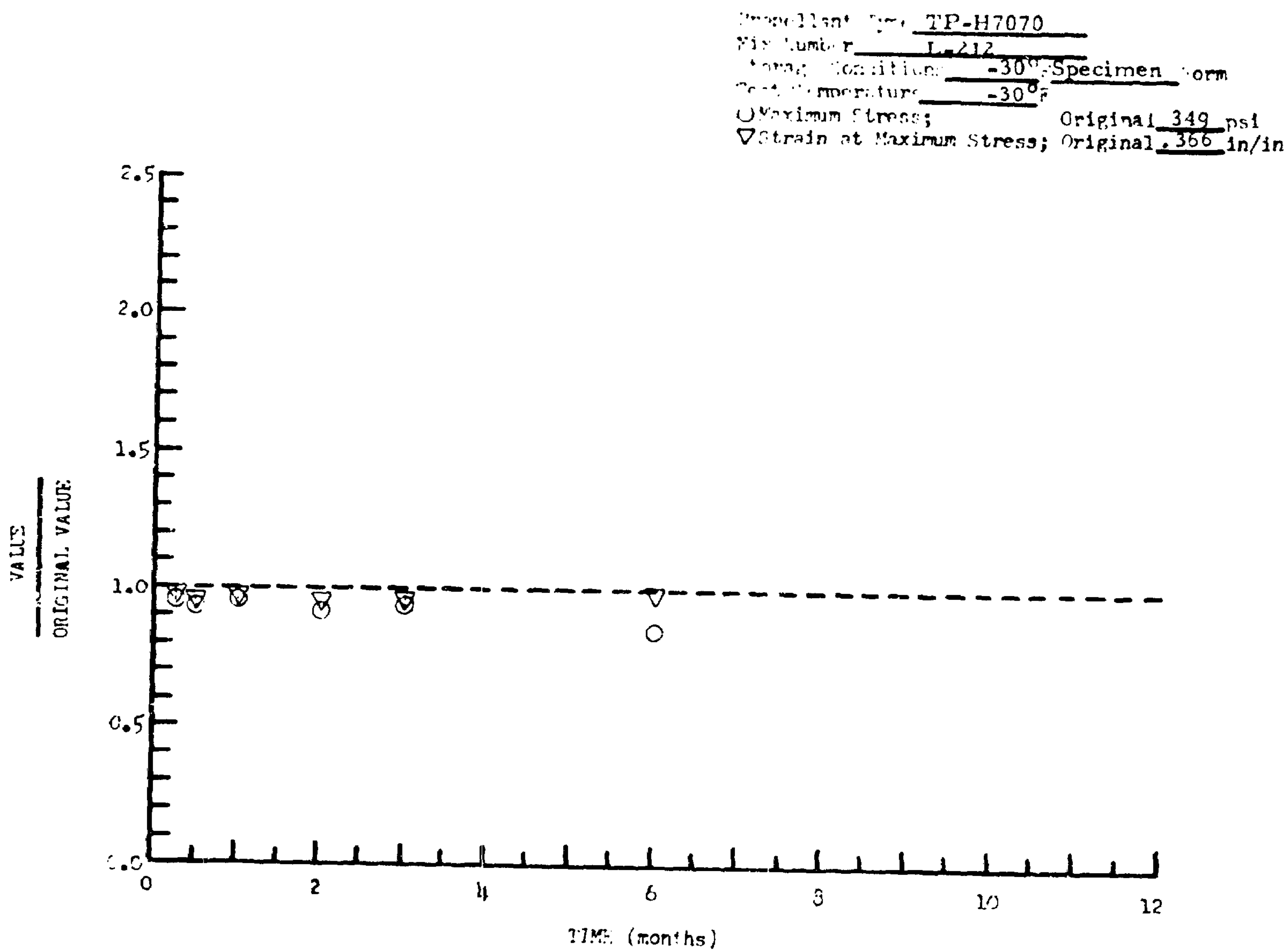


Figure 16. Effect of -30°F Storage on the Physical Properties of TP-H7070 Propellant Stored in Specimen Form

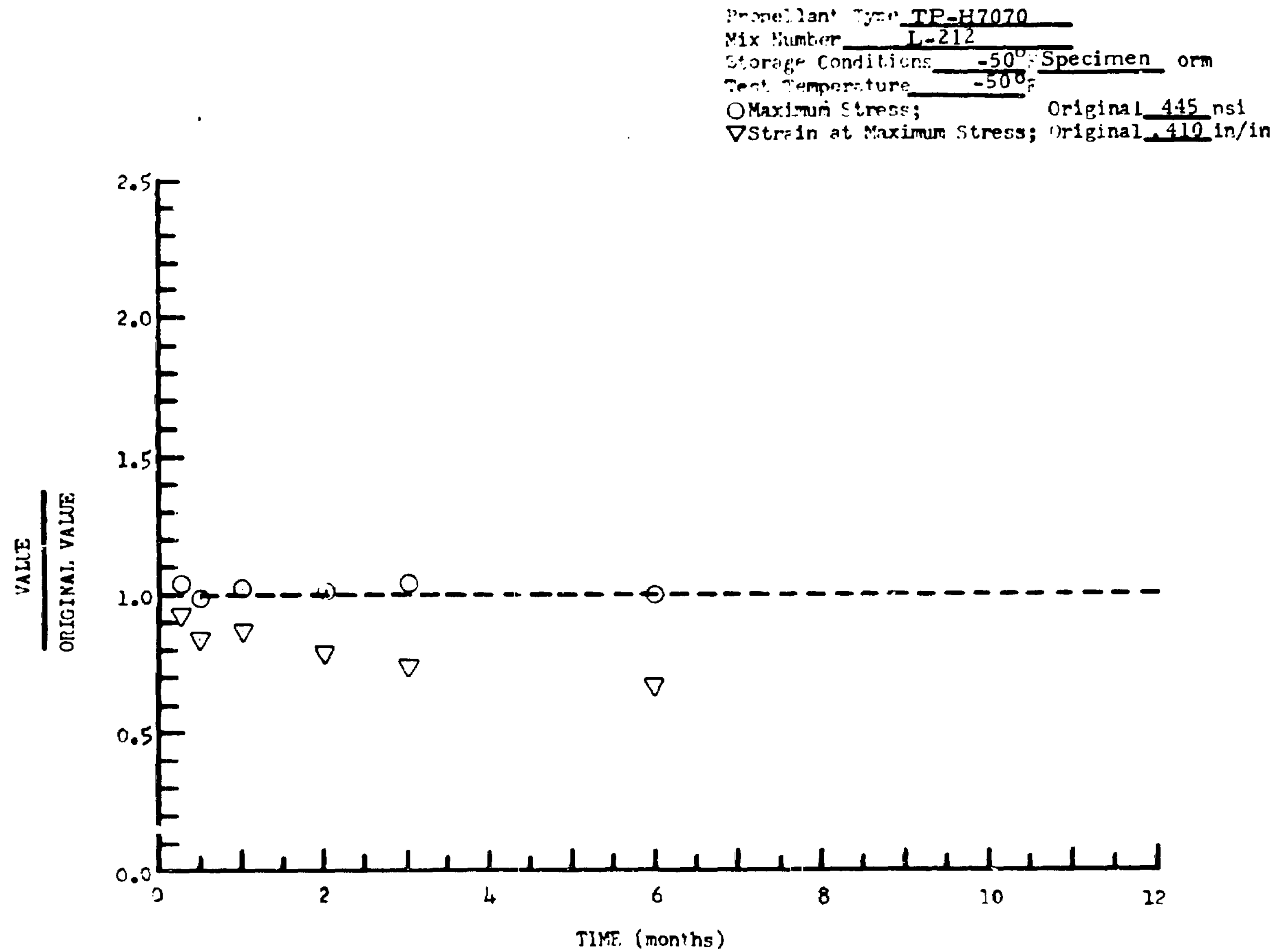


Figure 17. Effect of -50°F Storage on the Physical Properties of TP-H7070 Propellant Stored in Specimen Form

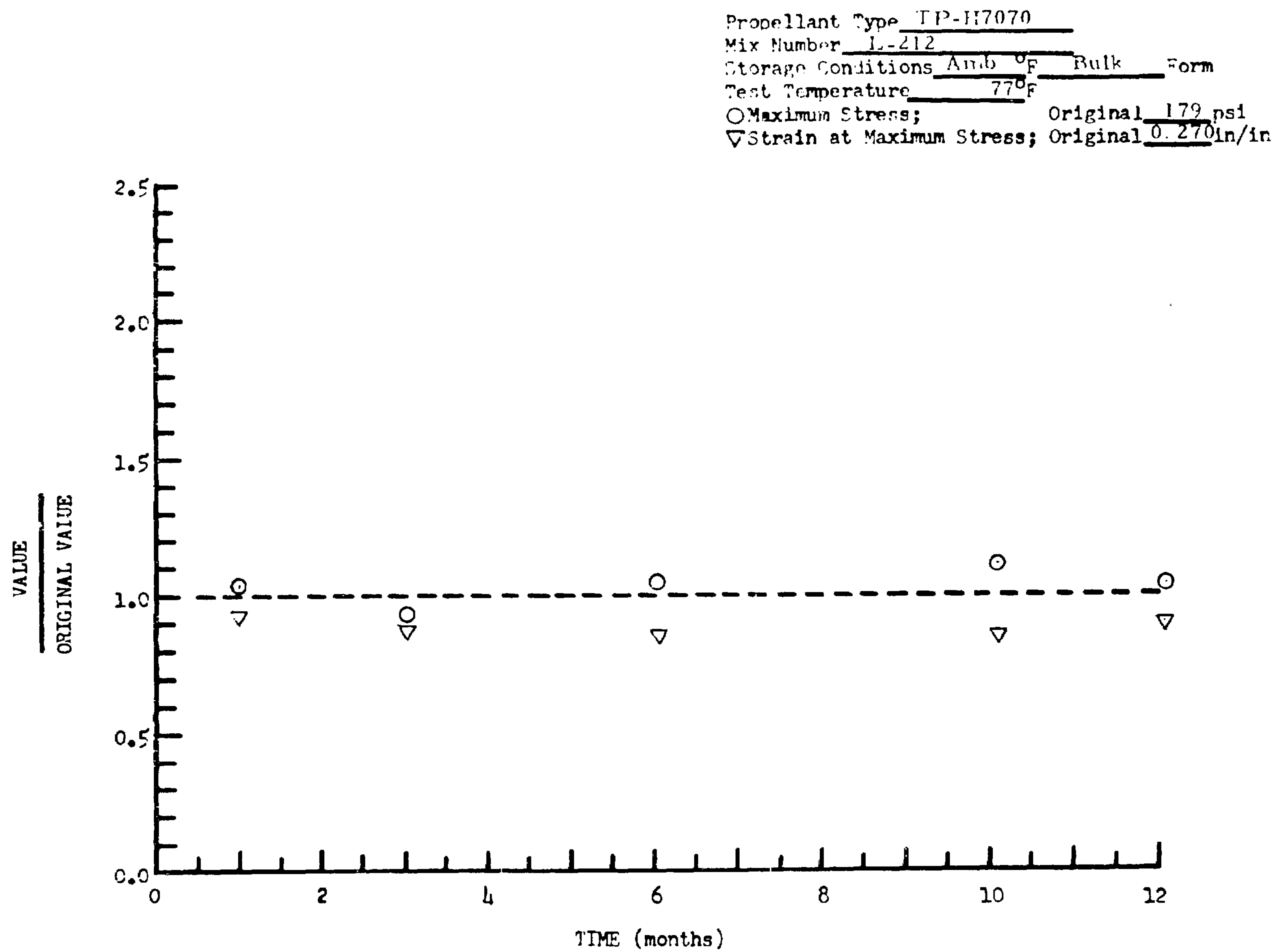


Figure 18. Effect of Ambient Storage on the Physical Properties at 77°F of TP-H7070 Propellant Stored in Bulk Sealed Form

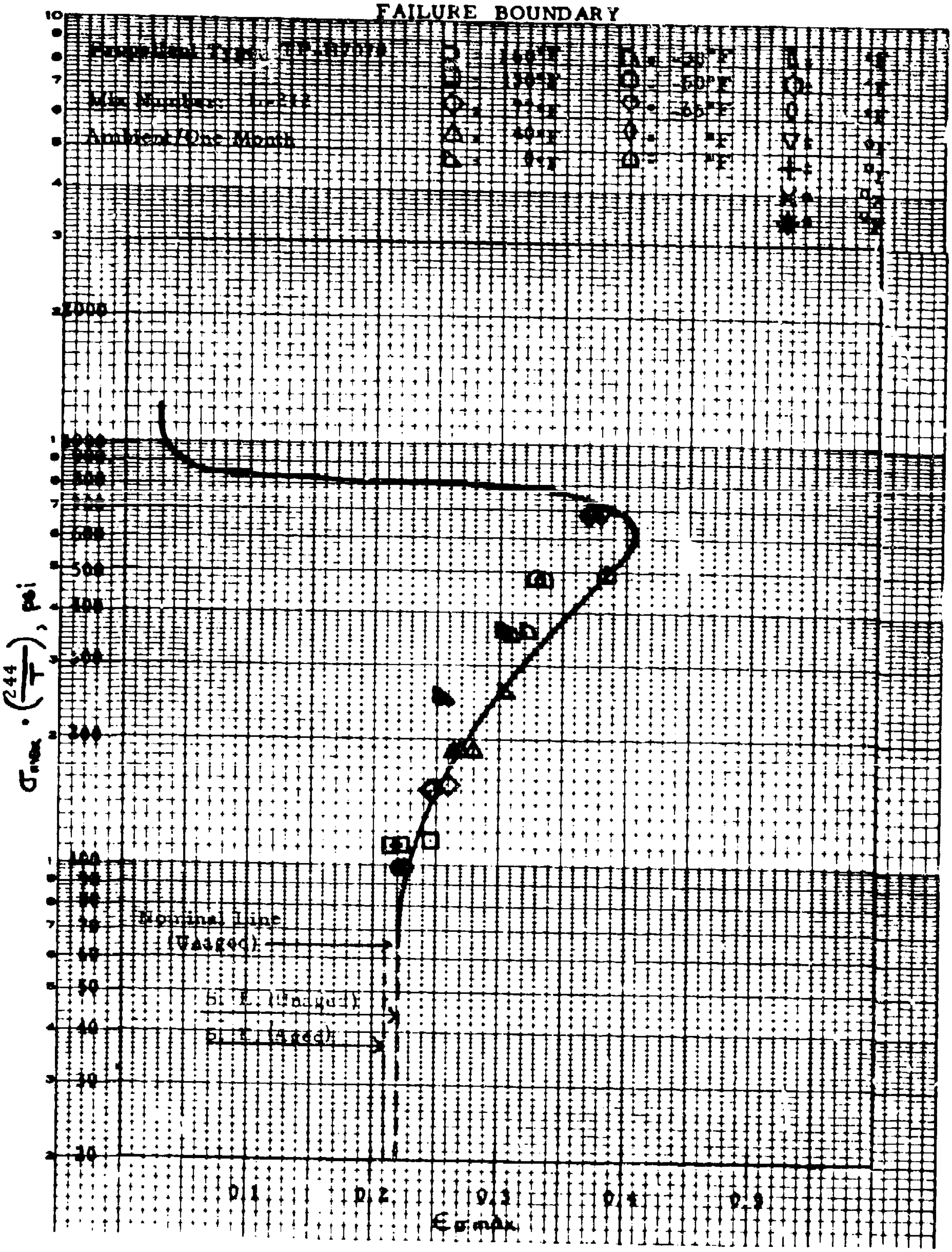


Figure 19. Failure Boundary, TP-H7070 Propellant Stored One Month at Ambient

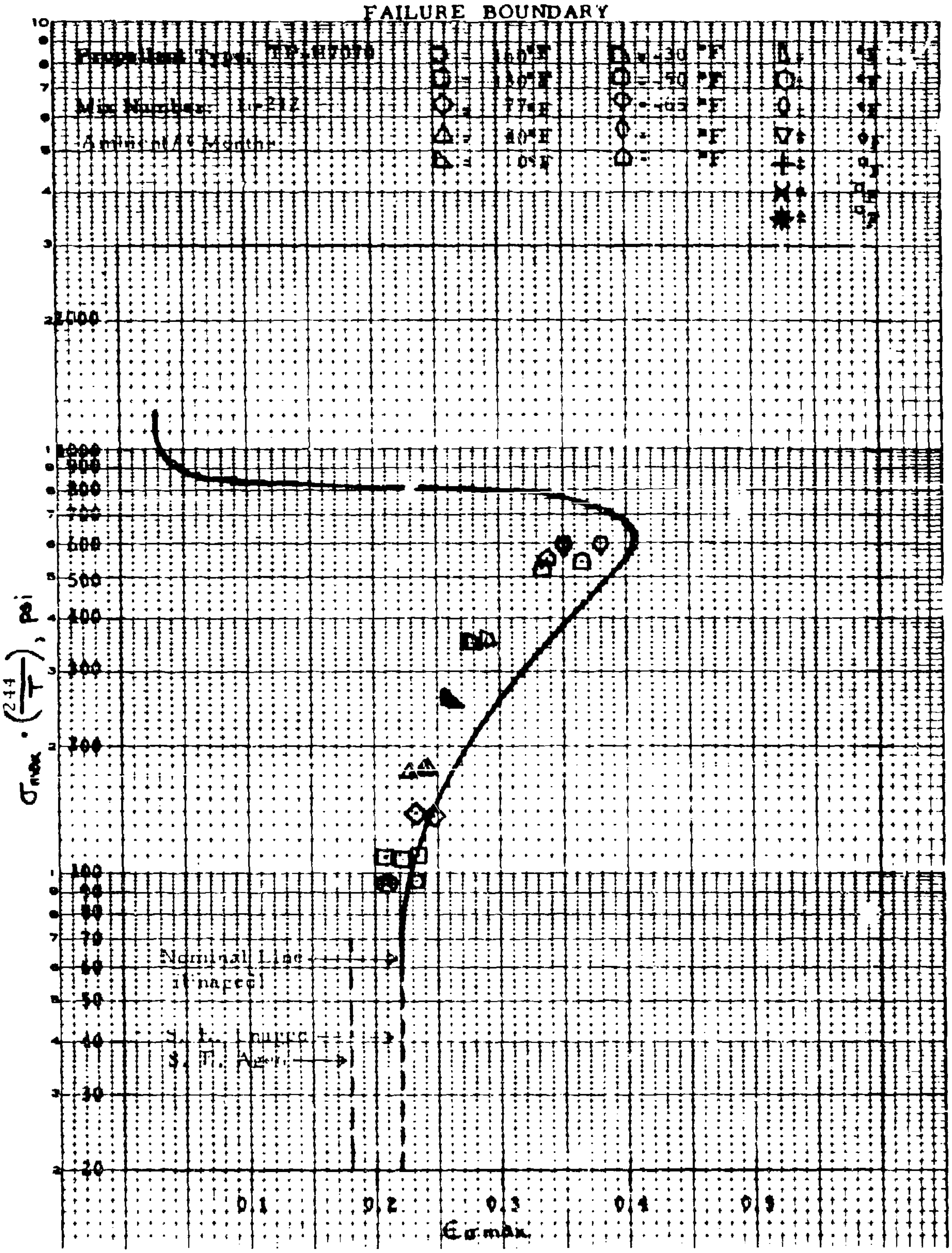


Figure 20. Failure Boundary, TP-H7070 Propellant Stored Three Months at Ambient

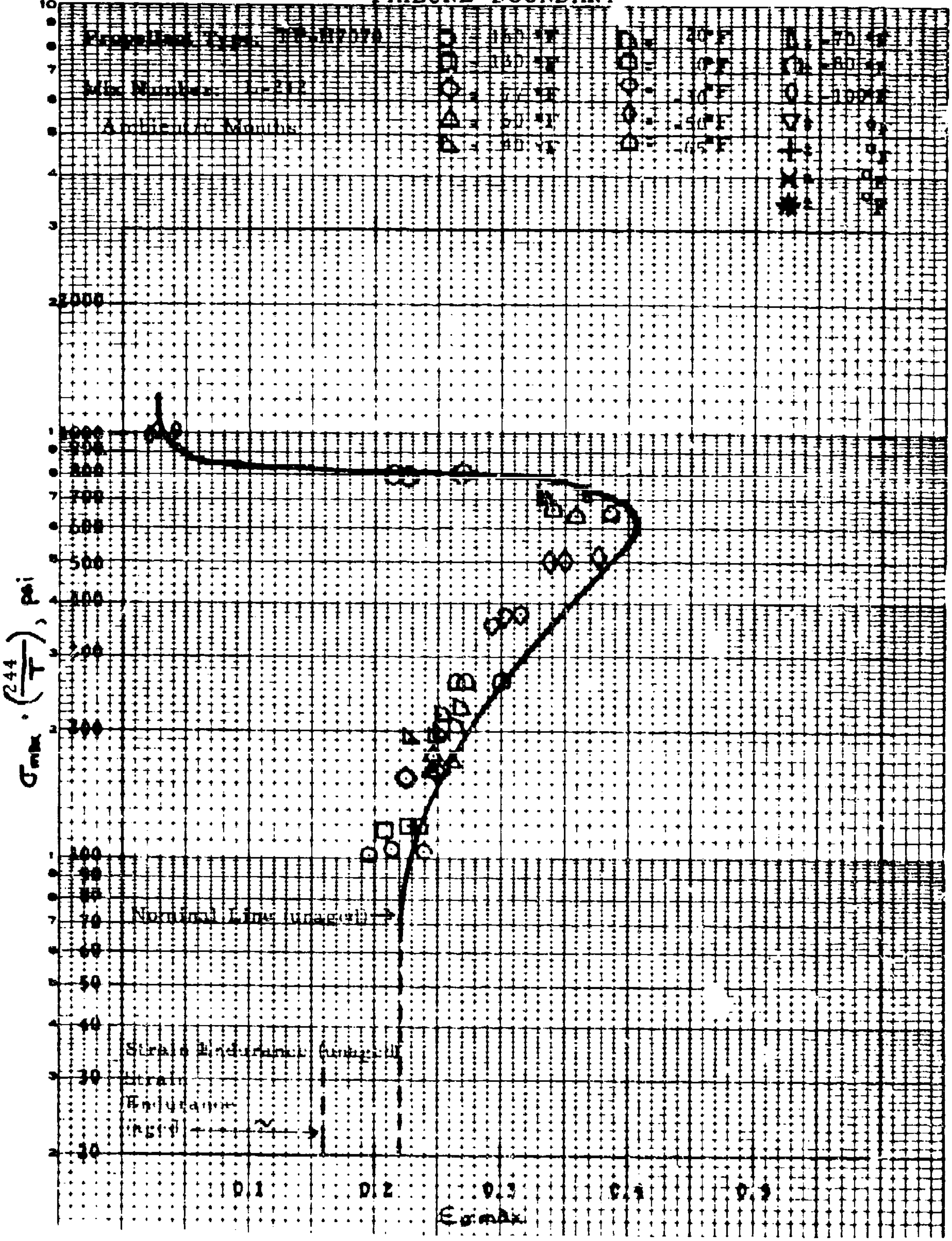


Figure 21. Failure Boundary, TP-H7070 Propellant Stored Six Months at Ambient

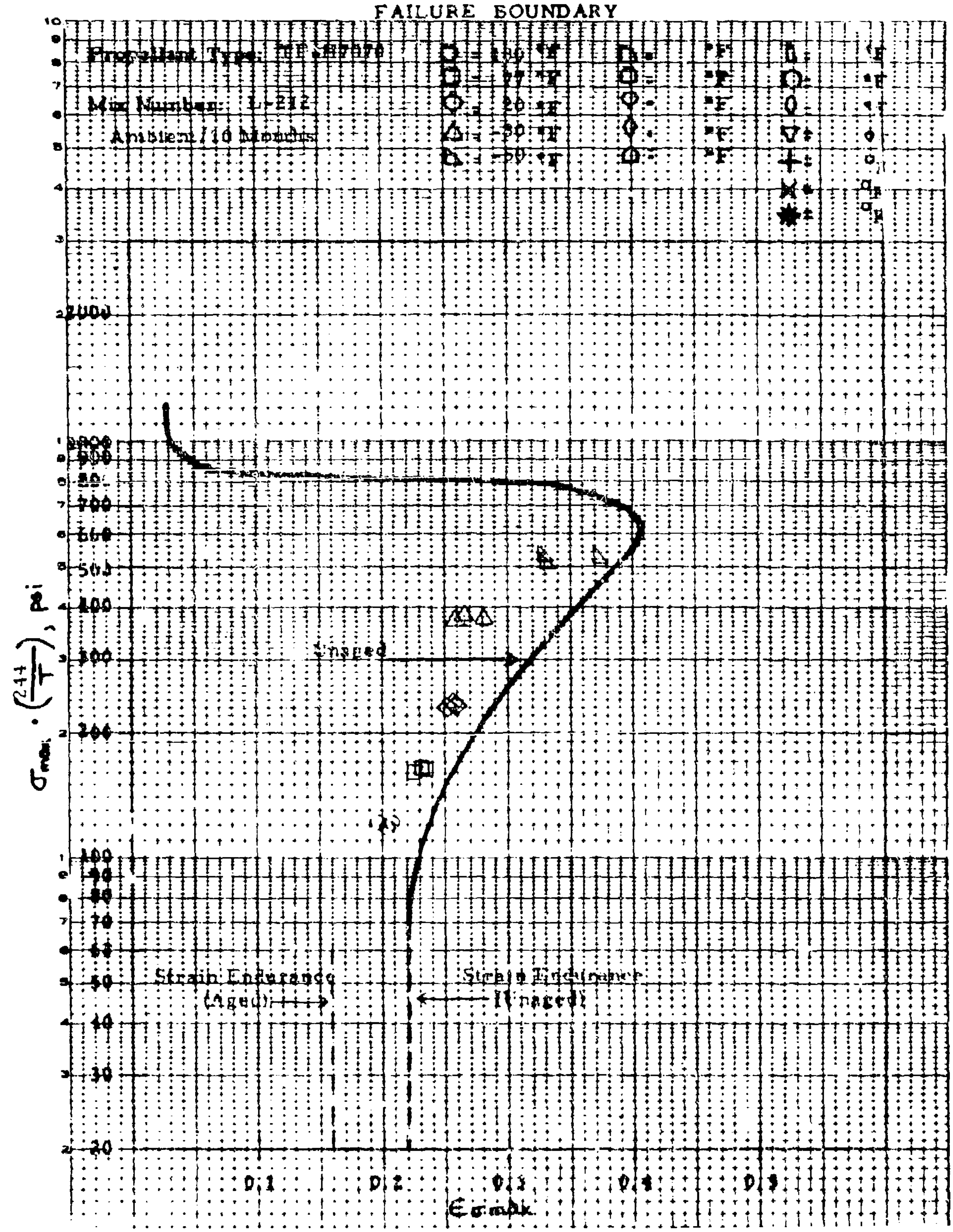


Figure 22. Failure Boundary, TP-H7070 Propellant Stored Ten Months at Ambient

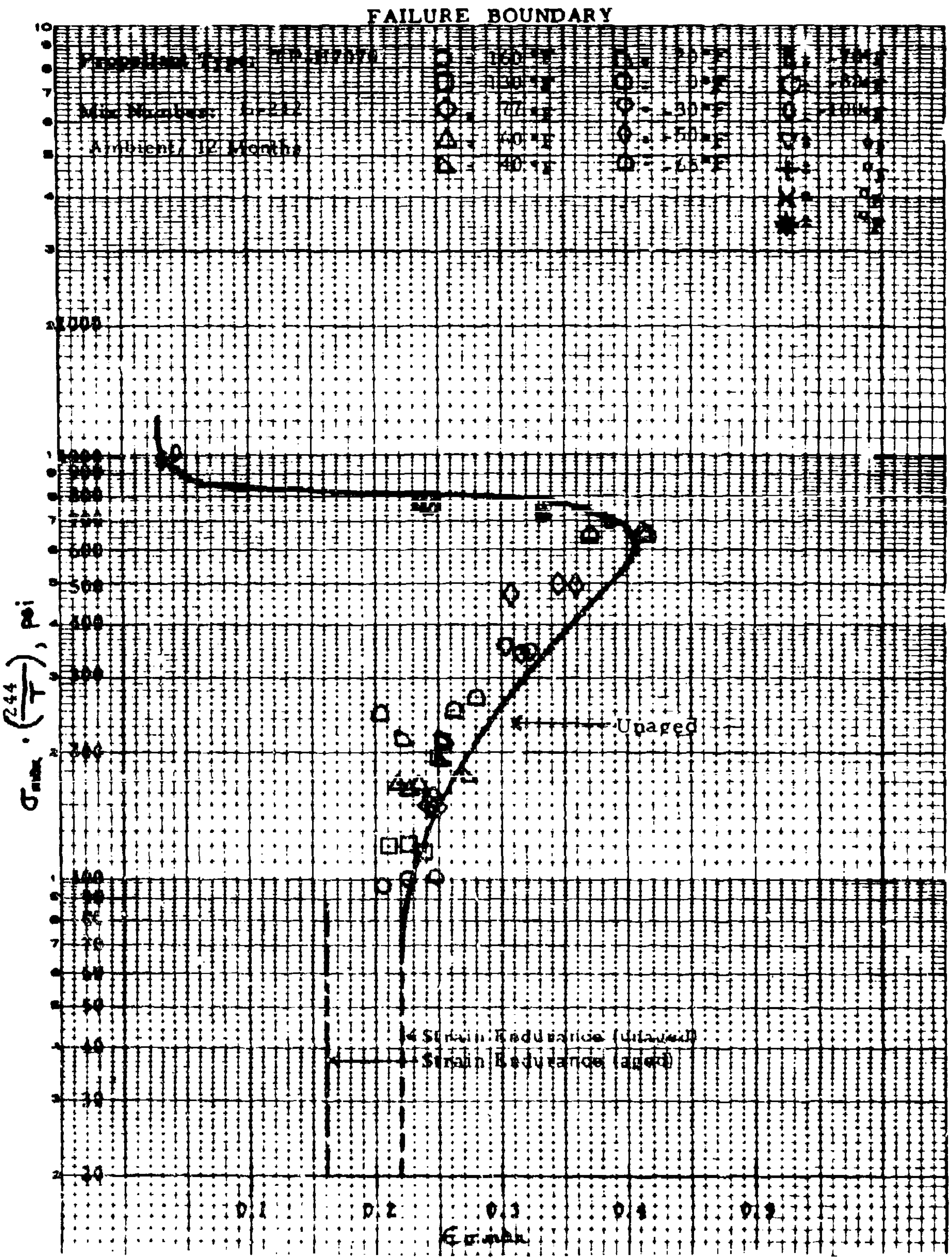


Figure 23 Failure Boundary, TP-H7070 Propellant Stored Twelve Months at Ambient

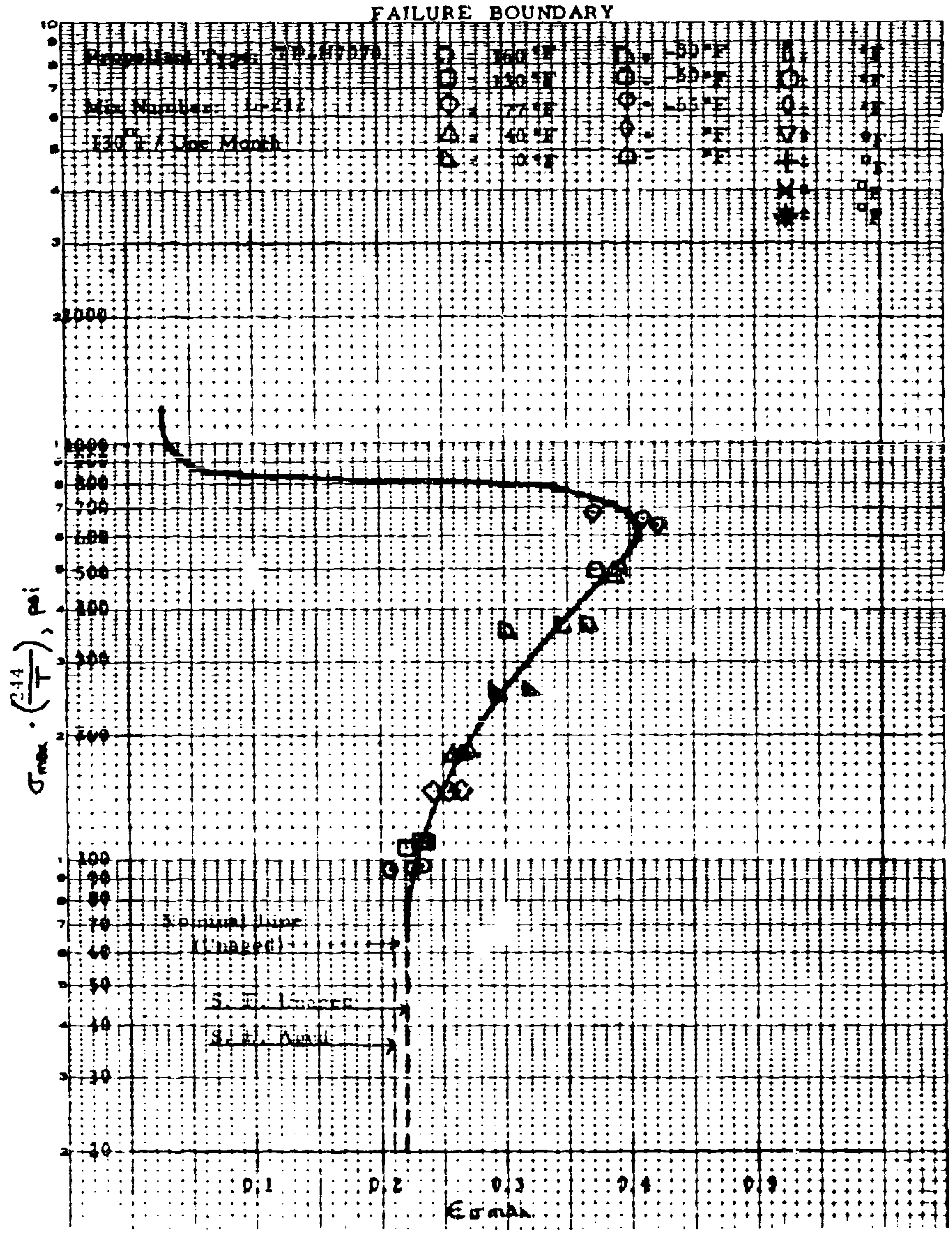


Figure 24. Failure Boundary, TP-H7070 Propellant Stored One

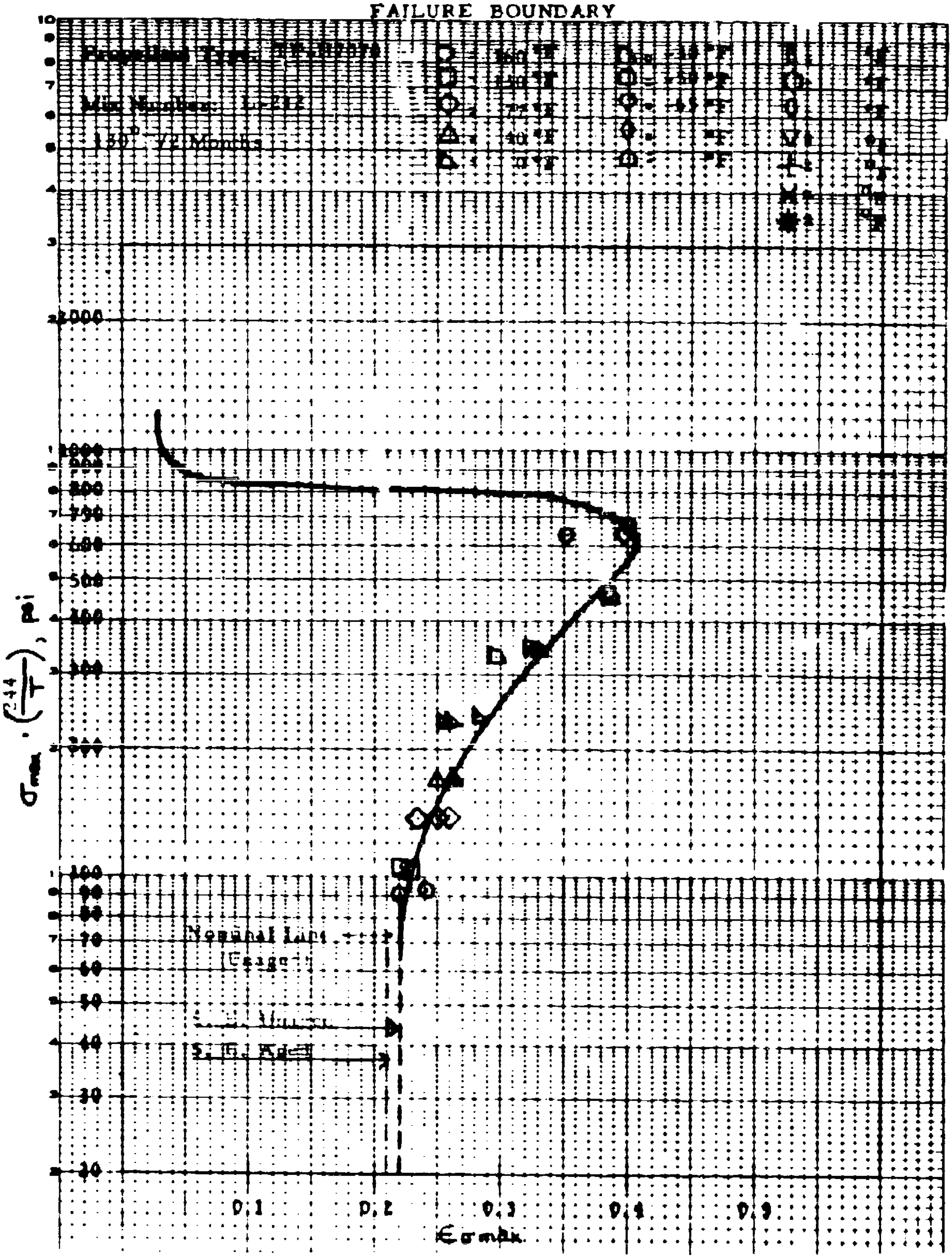
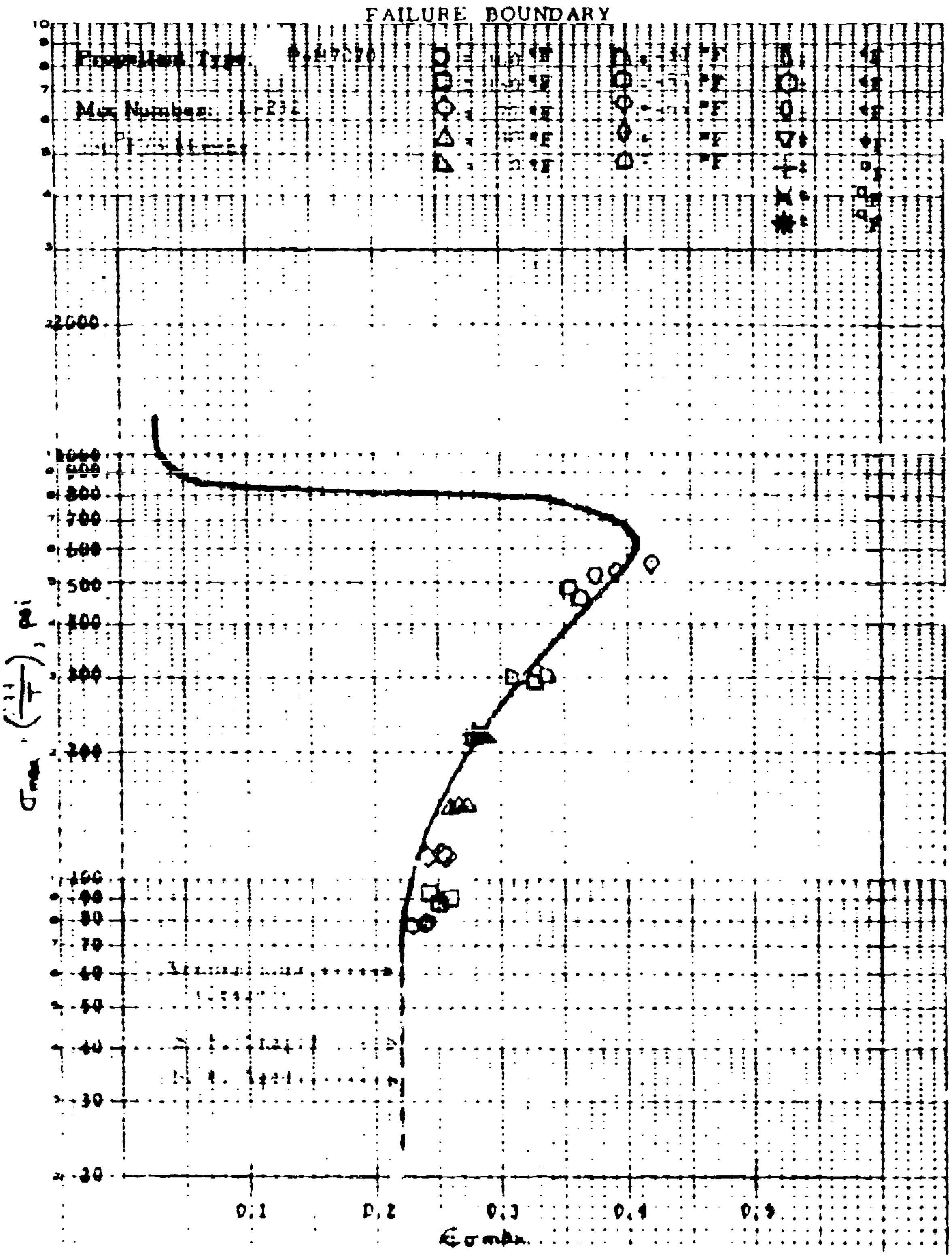


Figure 25. Failure Boundary, TP-H7070 Propellant Stored Two Months at 130°F



Failure Boundary

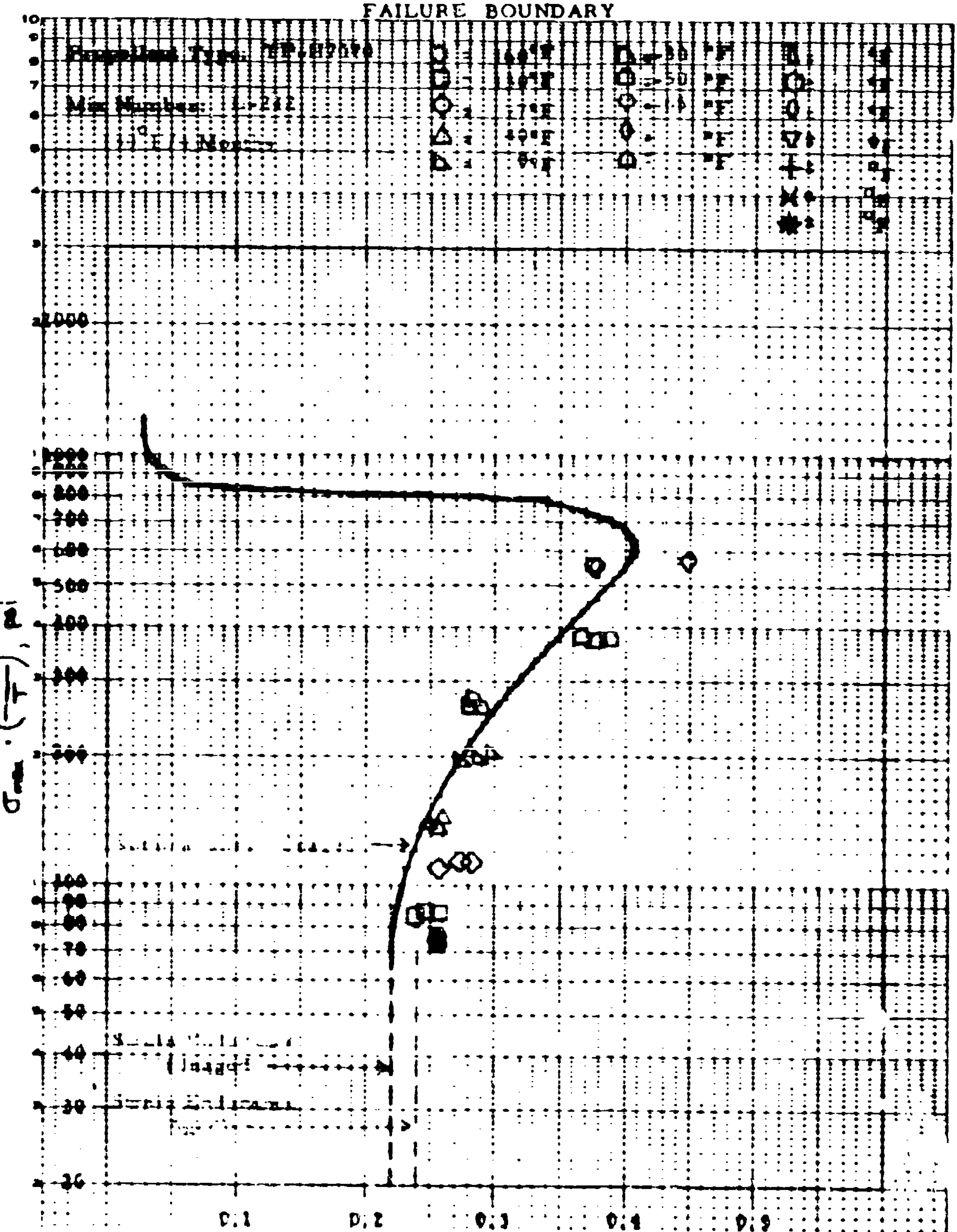
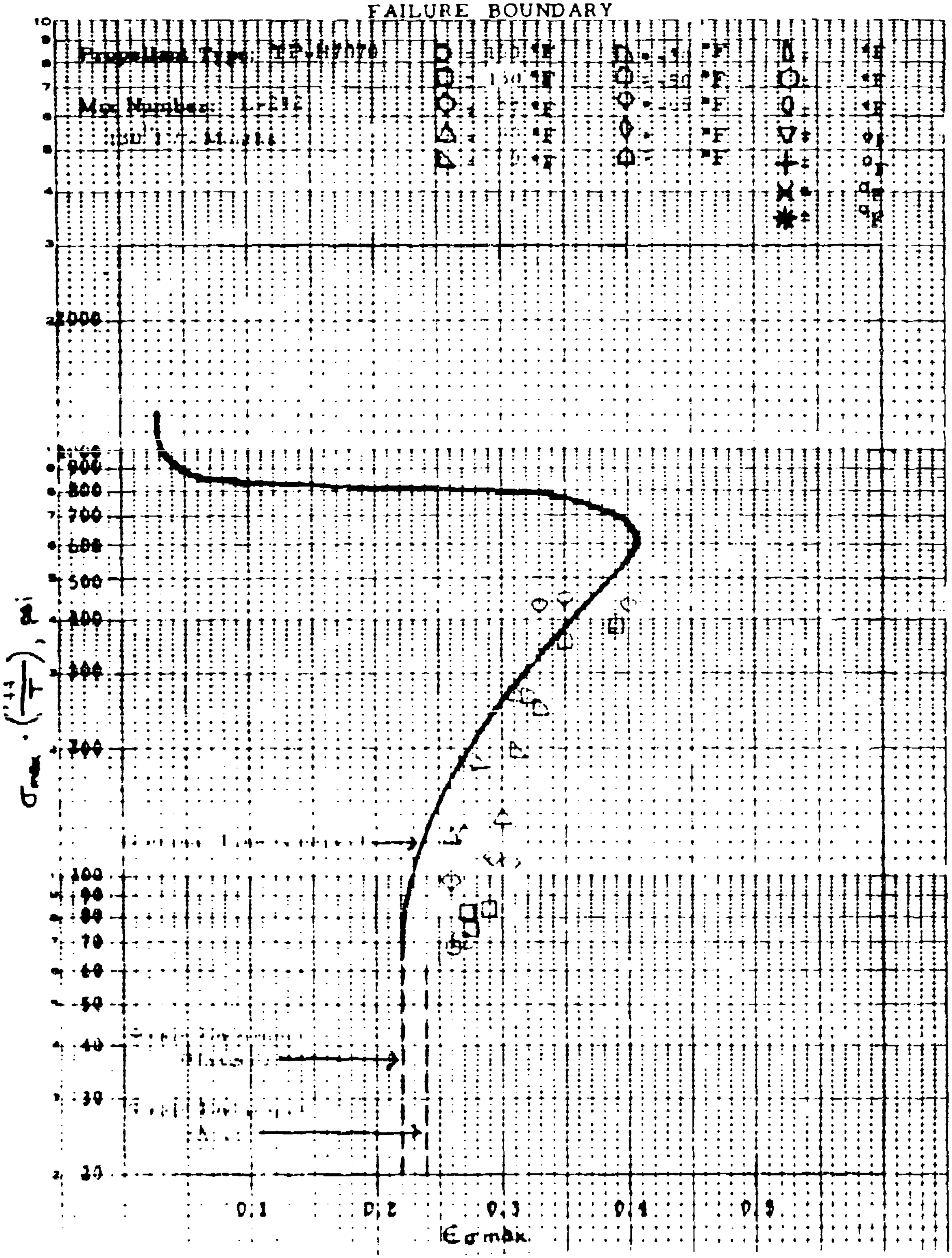


Figure 57. Failure Boundary, HP-H7070 Propellant Stored Four Months at 30°F

FAILURE BOUNDARY



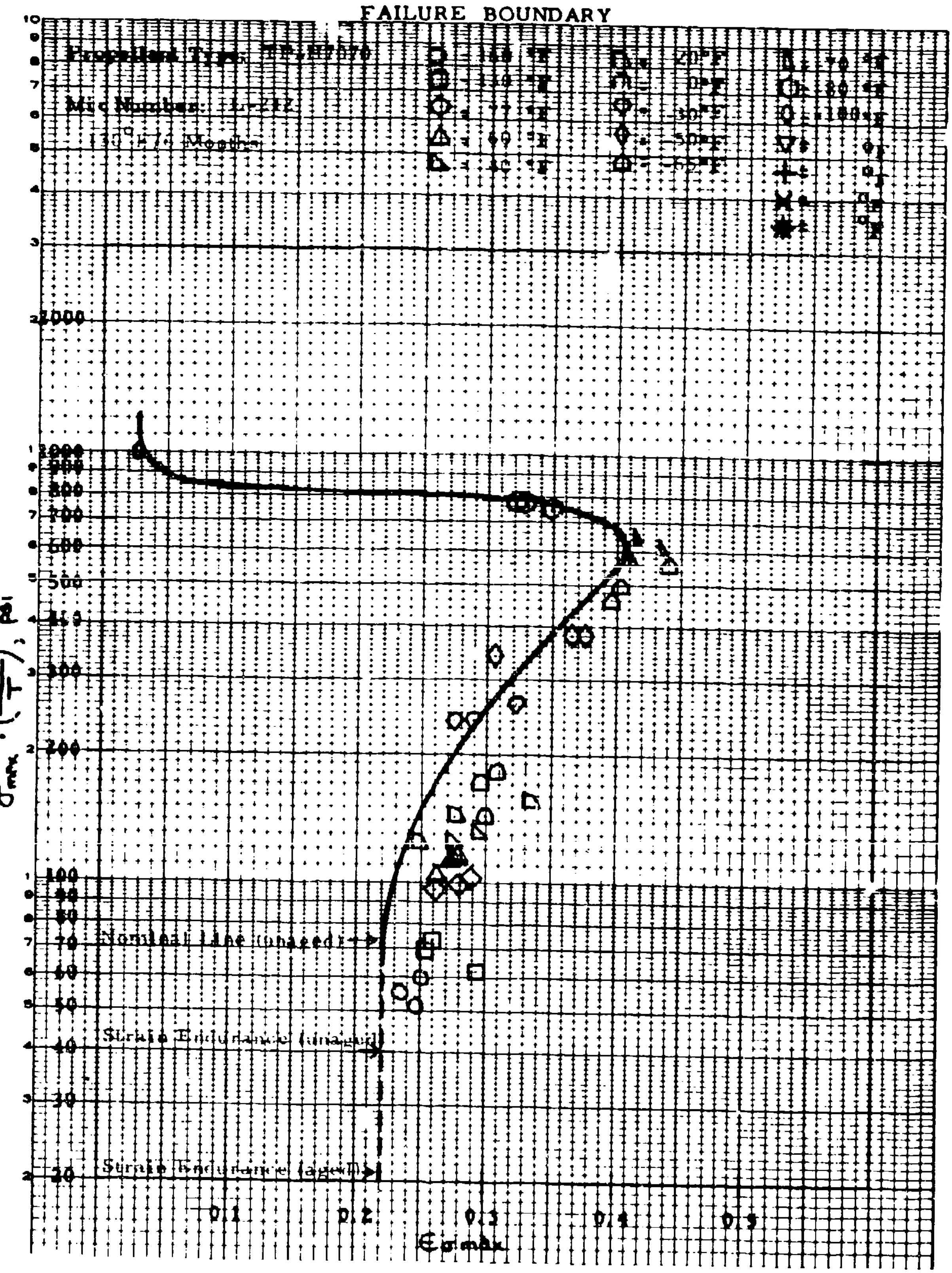


Figure 29. Failure Boundary, TP-H7070 Propellant Stored Six Months at 130°F

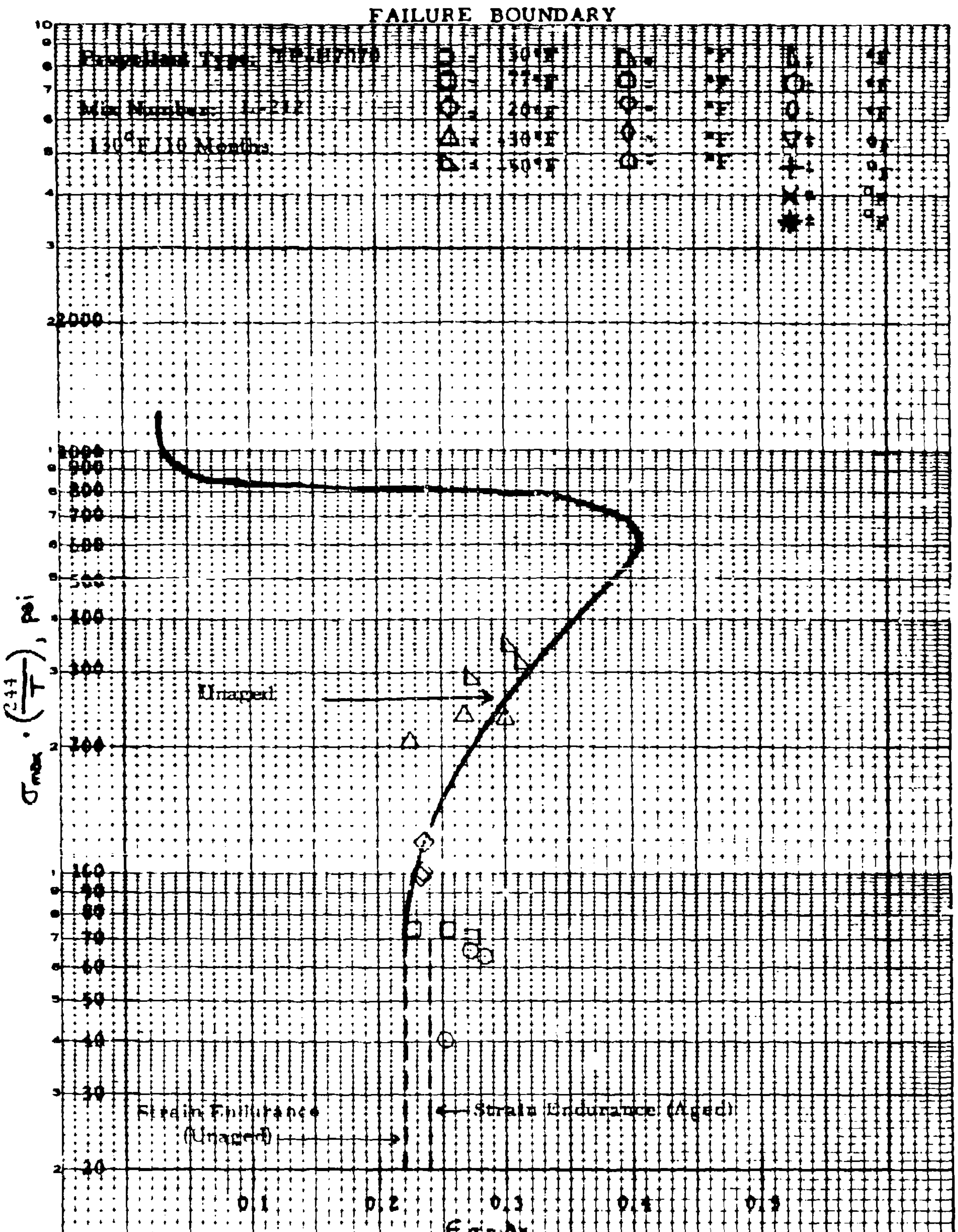


Figure 30. Failure Boundary, TP-H7070 Propellant Stored Ten Months at 130°F

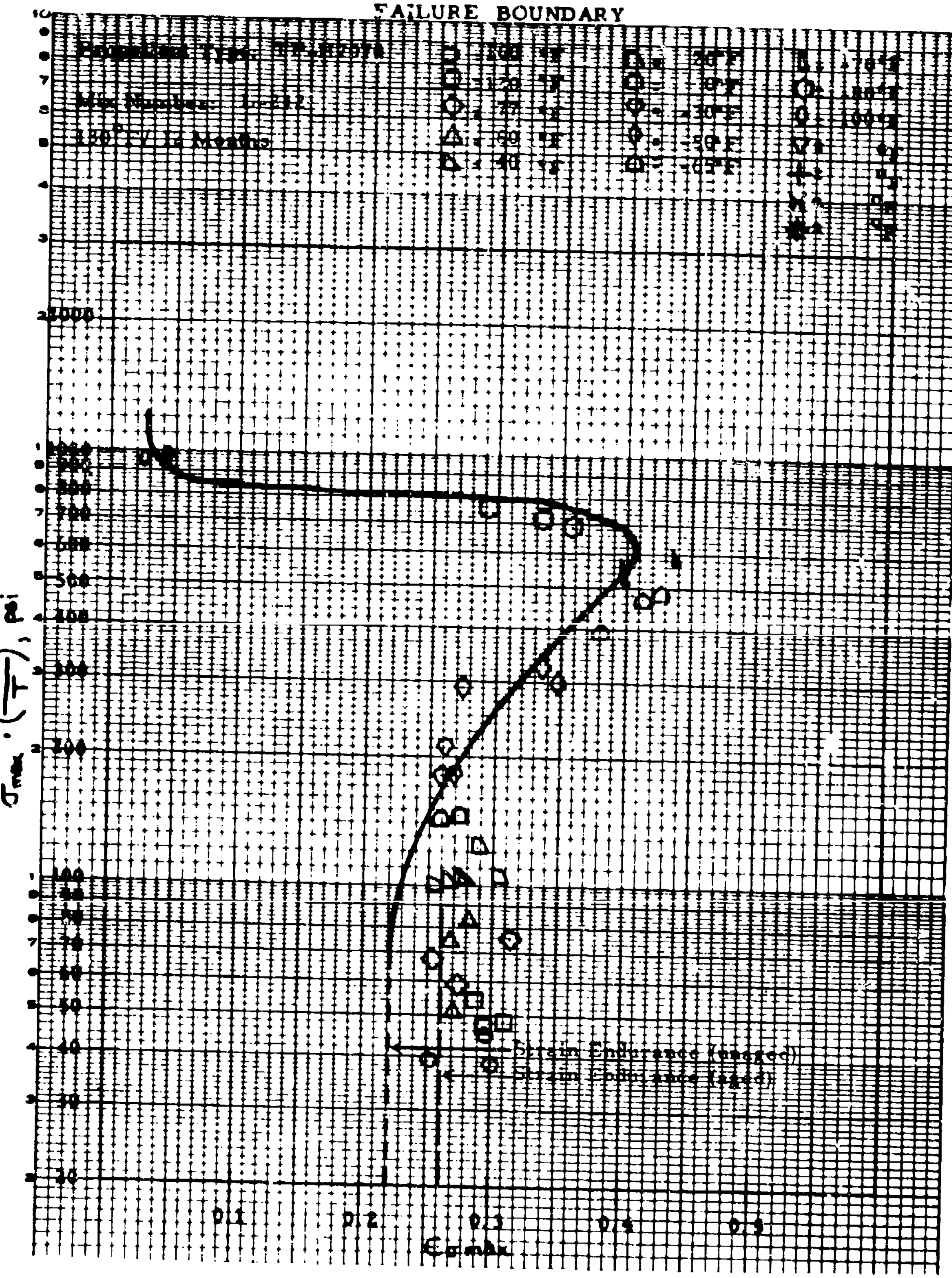


Figure 31. Failure Boundary, TP-H7070 Propellant Stored Twelve Months at 130°F

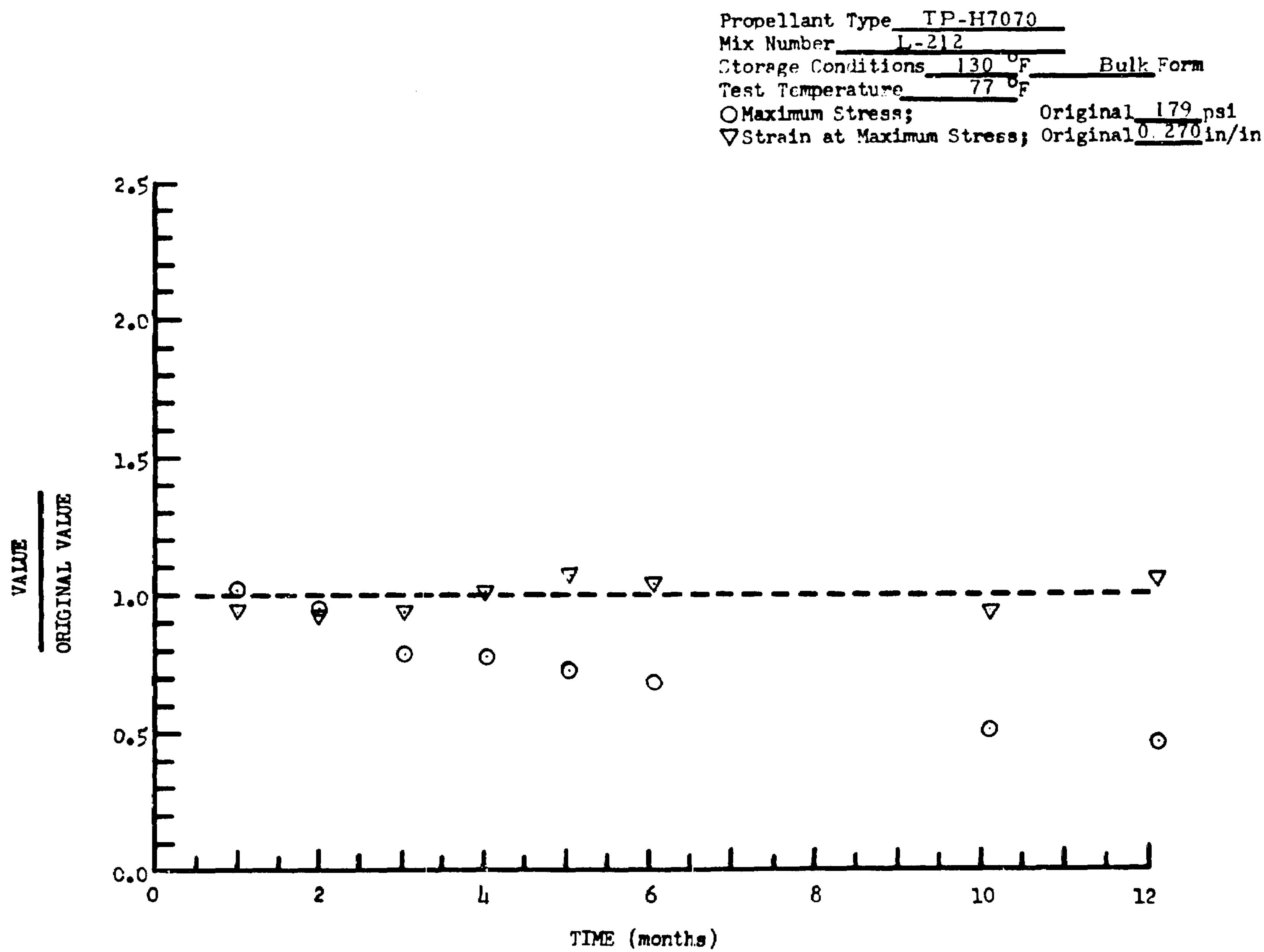


Figure 32. Effect of 130°F Storage on the Physical Properties at 77°F of TP-H7070 Propellant Stored in Bulk Sealed Form

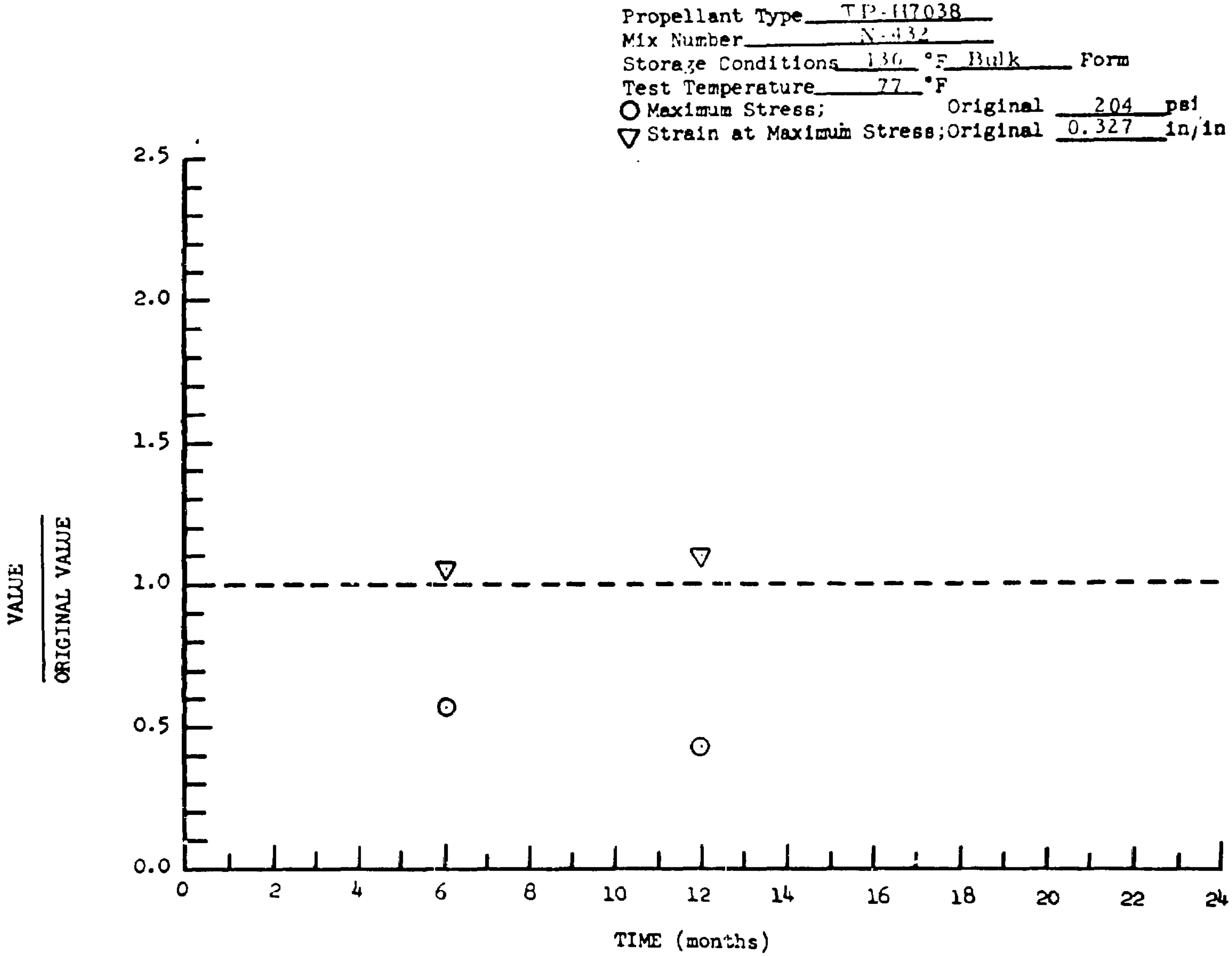


Figure 33. Effect of 130°F Storage on the Physical Properties at 77°F of TP-H7038 Propellant (Mix N-432) Stored in Bulk Sealed Form

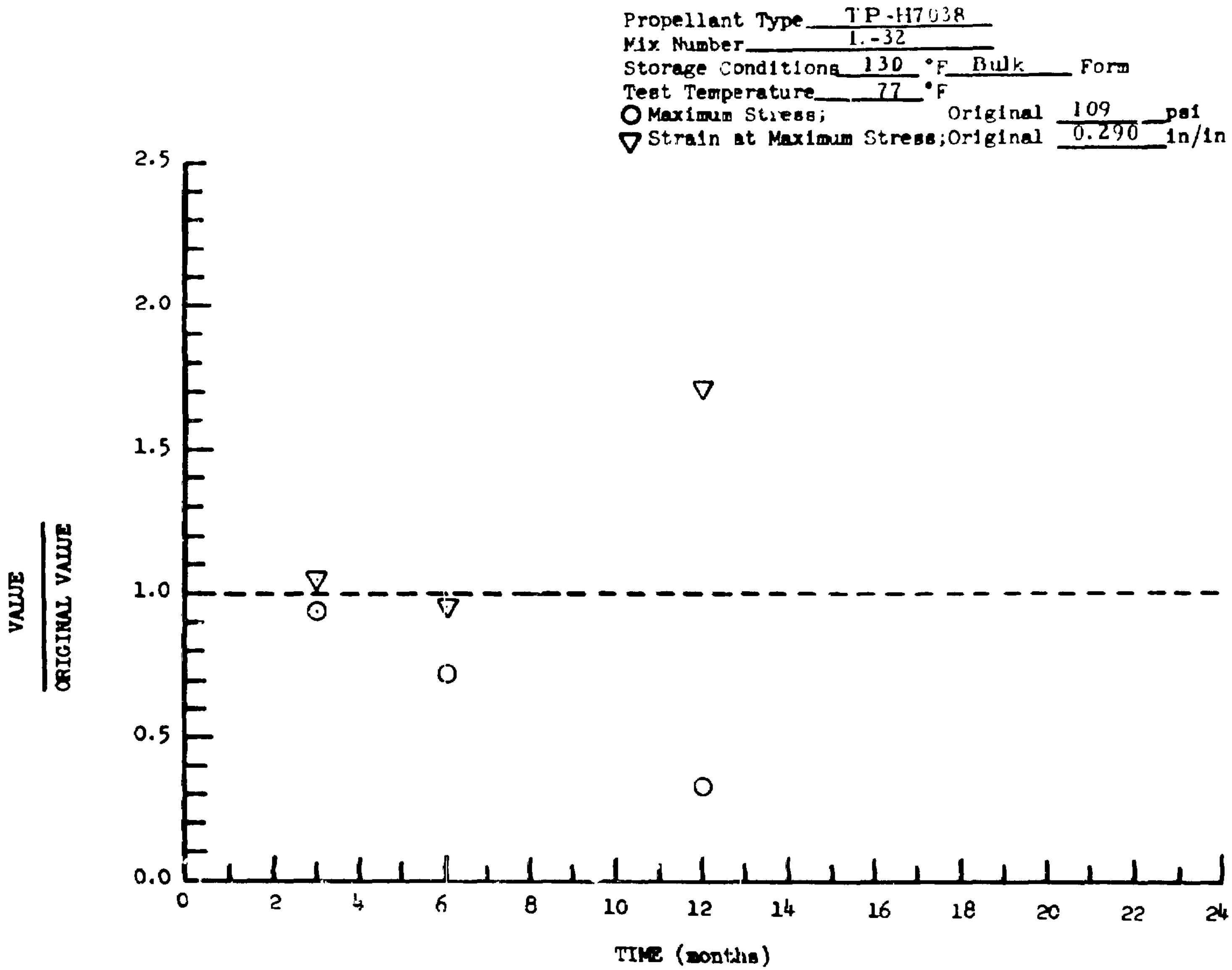


Figure 34. Effect of 130°F Storage on the Physical Properties at 77°F of TP-H7038 Propellant (Mix L-32) Stored in Bulk Sealed Form

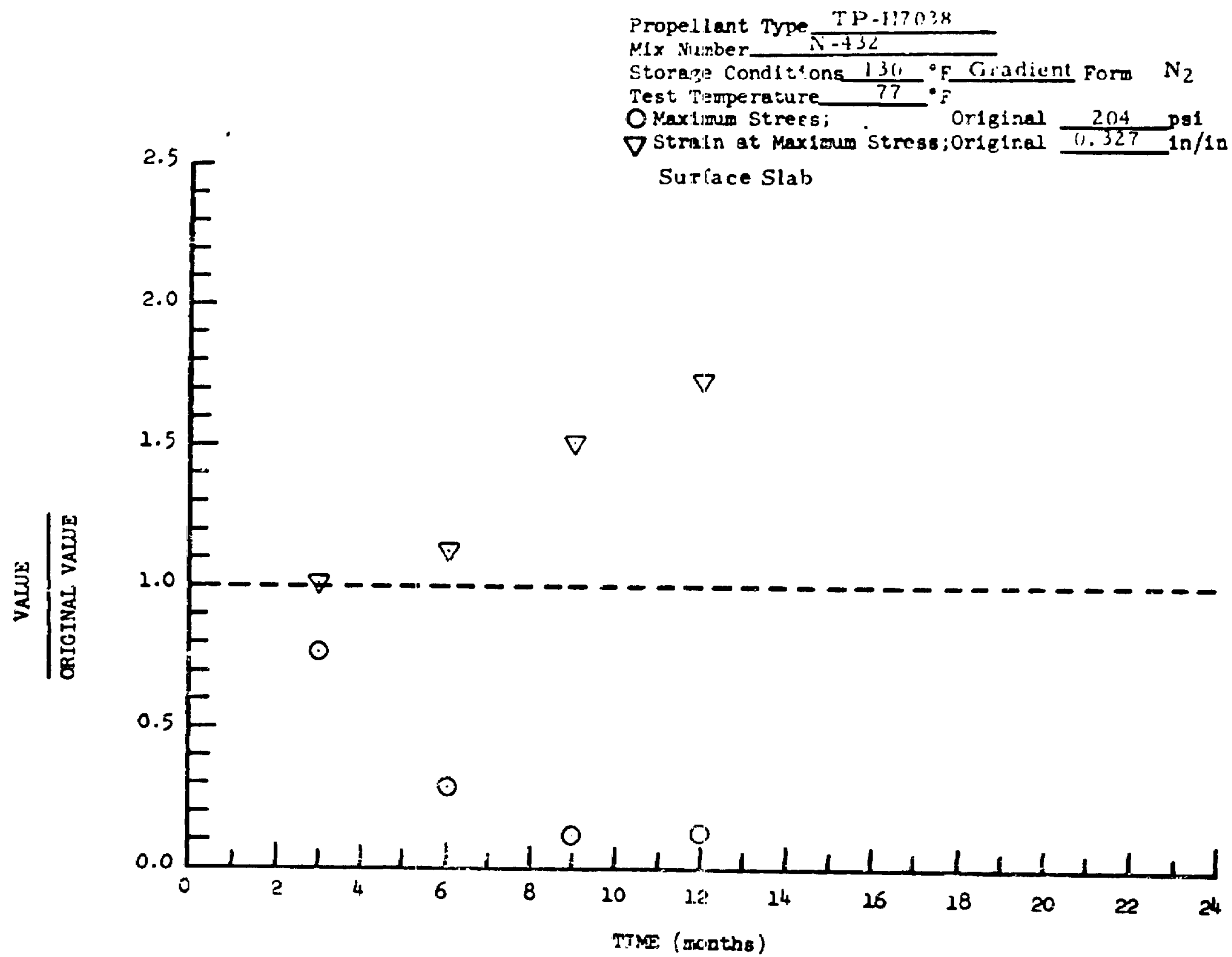


Figure 35. Effect of 130°F Storage on the Physical Properties at 77°F of TP-H7038 Propellant (Mix N-432) Stored in Bulk Gradient Form (N_2, Surface Slab)

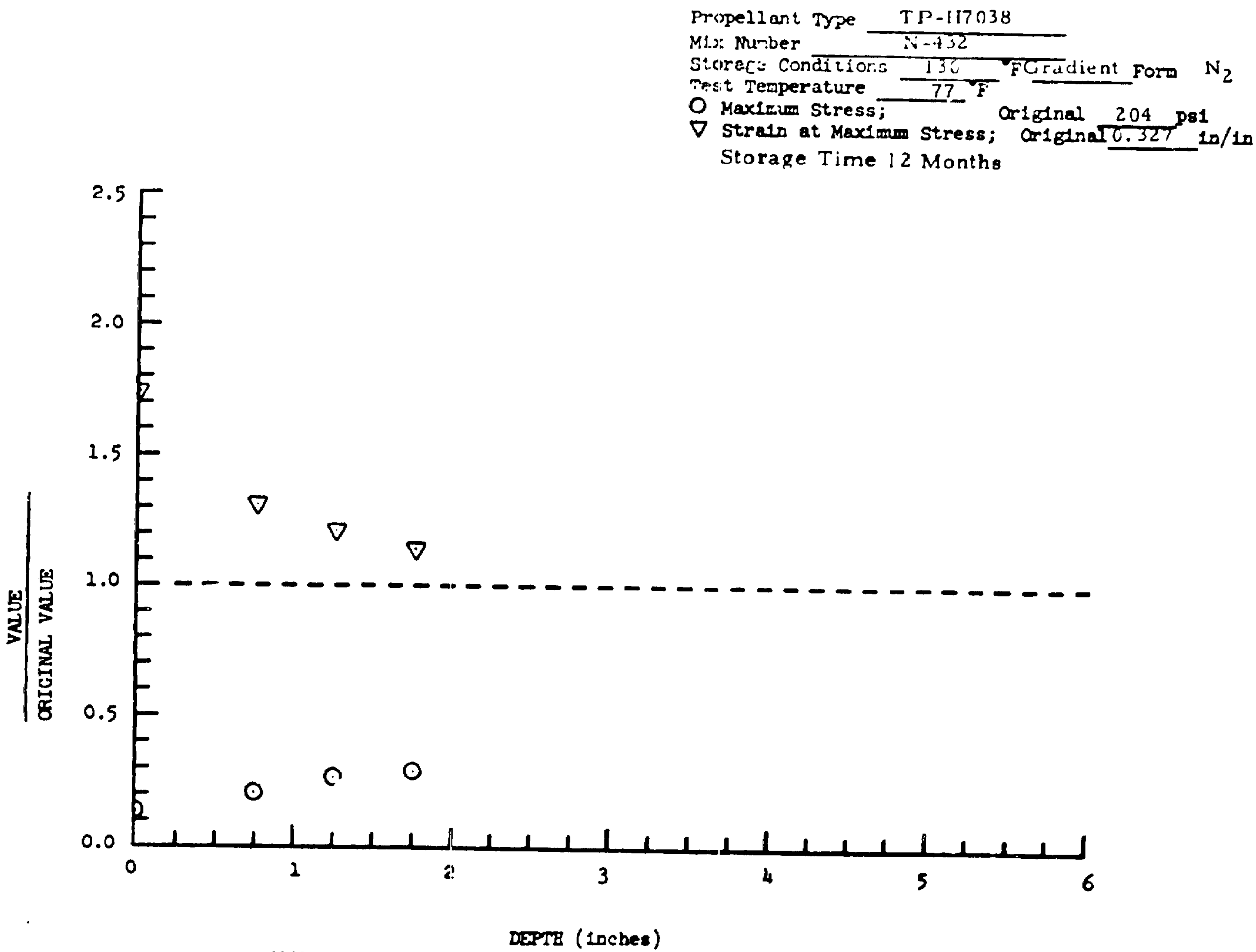


Figure 36. Effect of 130°F Storage for 12 Months on the Physical Properties at 77°F of TP-H7038 Propellant (Mix N-432) Stored in Bulk Gradient Form (N_2)

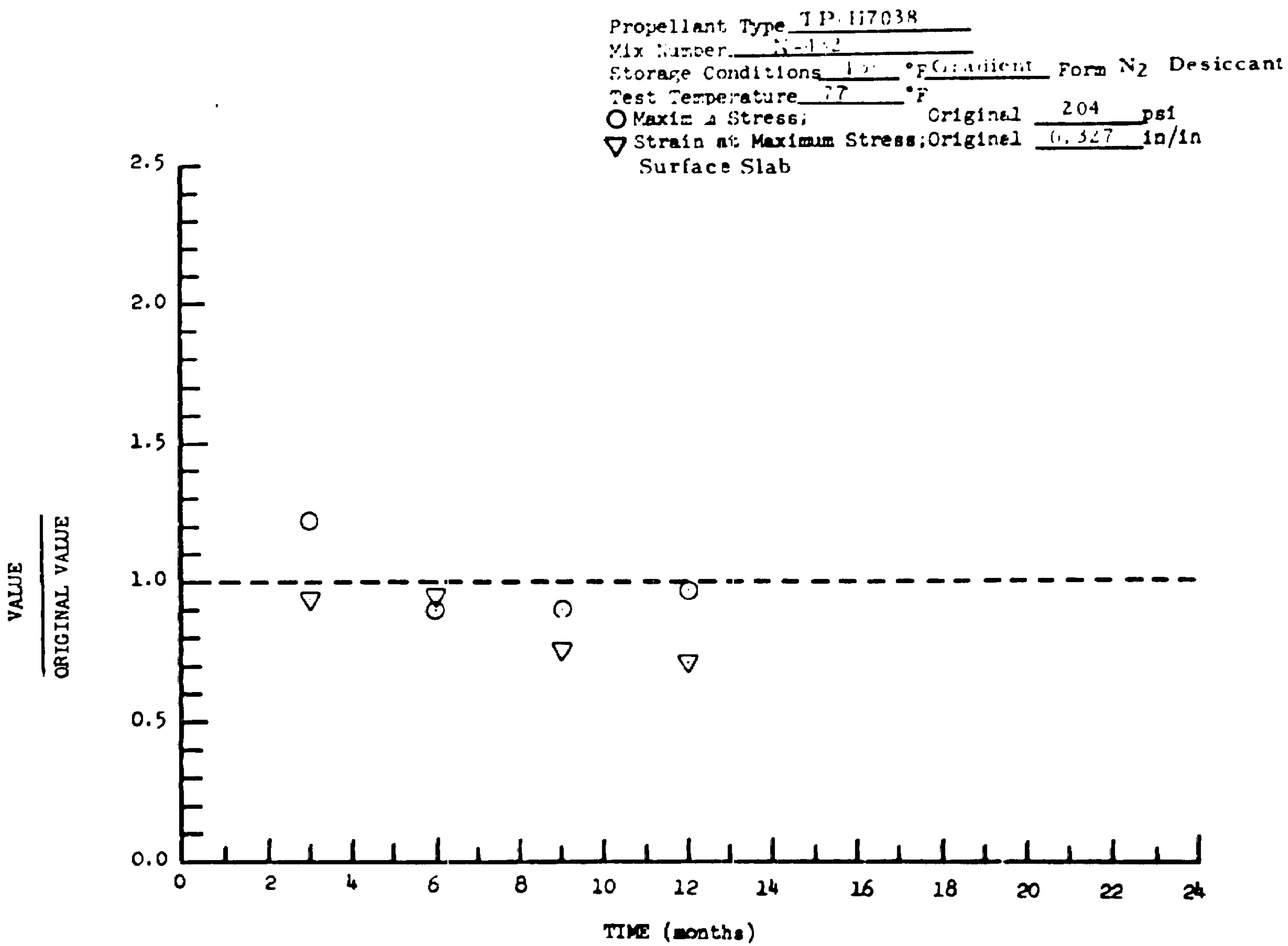


Figure 37. Effect of 130°F Storage on the Physical Properties at 77°F of TP-H7038 Propellant (Mix N-432) Stored in Bulk Gradient Form (N_2, Desiccant)

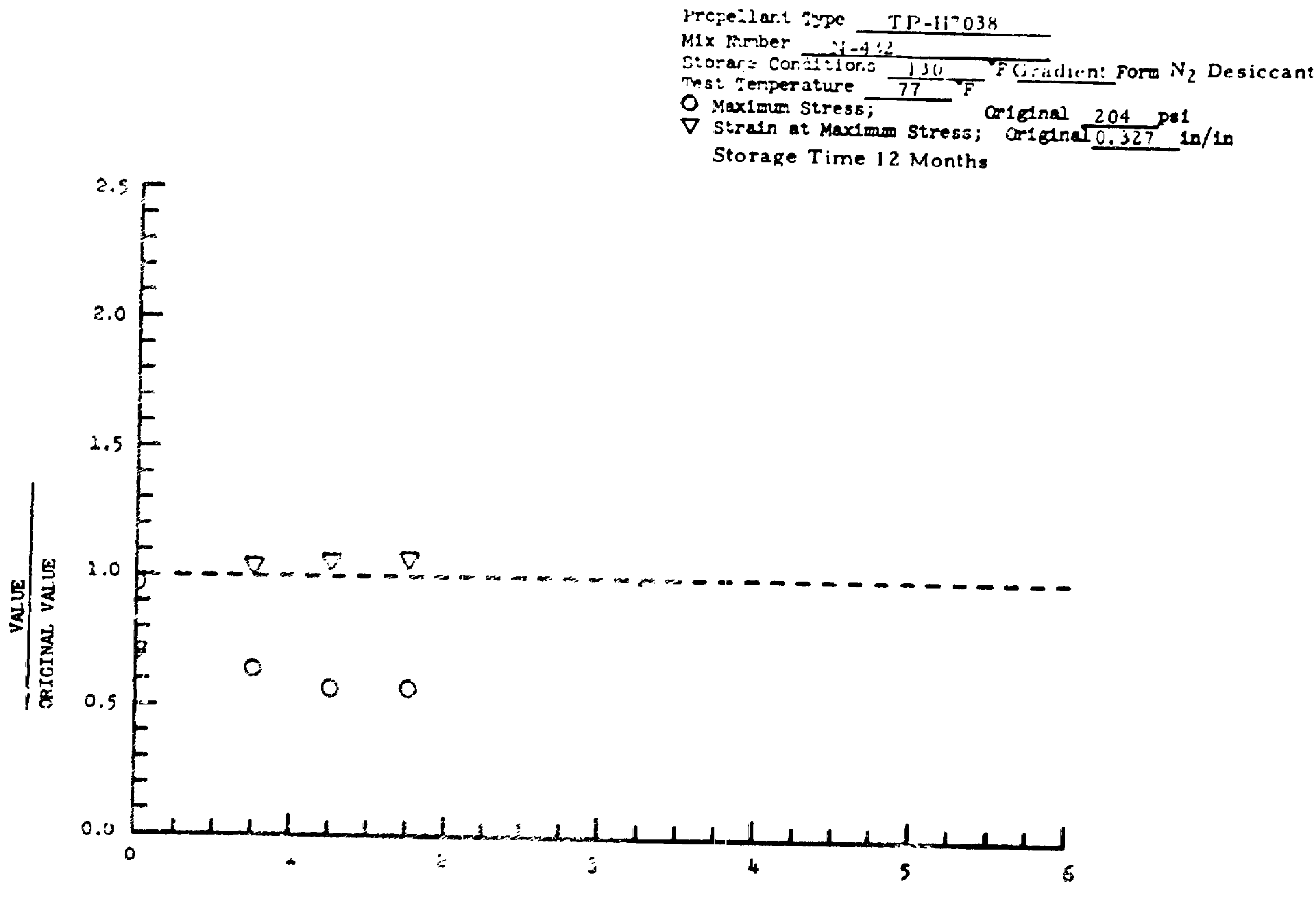


Figure 38. Effect of 130°F Storage for 12 Months on the Physical Properties of TP-H7038 Propellant (Mix N-432) Stored in Bulk Gradient Form (N_2, Desiccant)

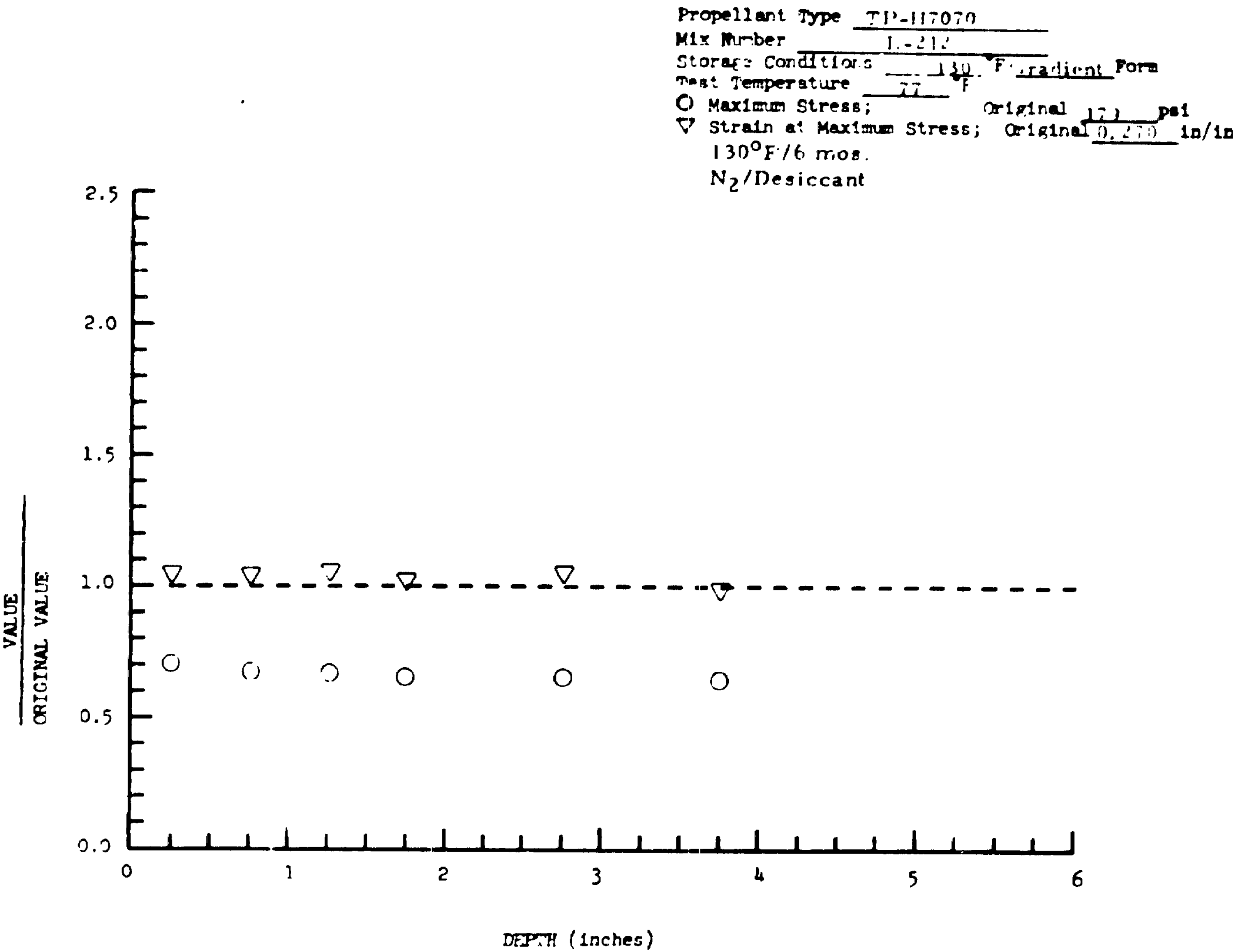


Figure 39. Effect of 130°F Storage for Six Months on the Physical Properties of TP-H7070 Propellant Stored in Bulk Gradient Form (N_2, Desiccant)

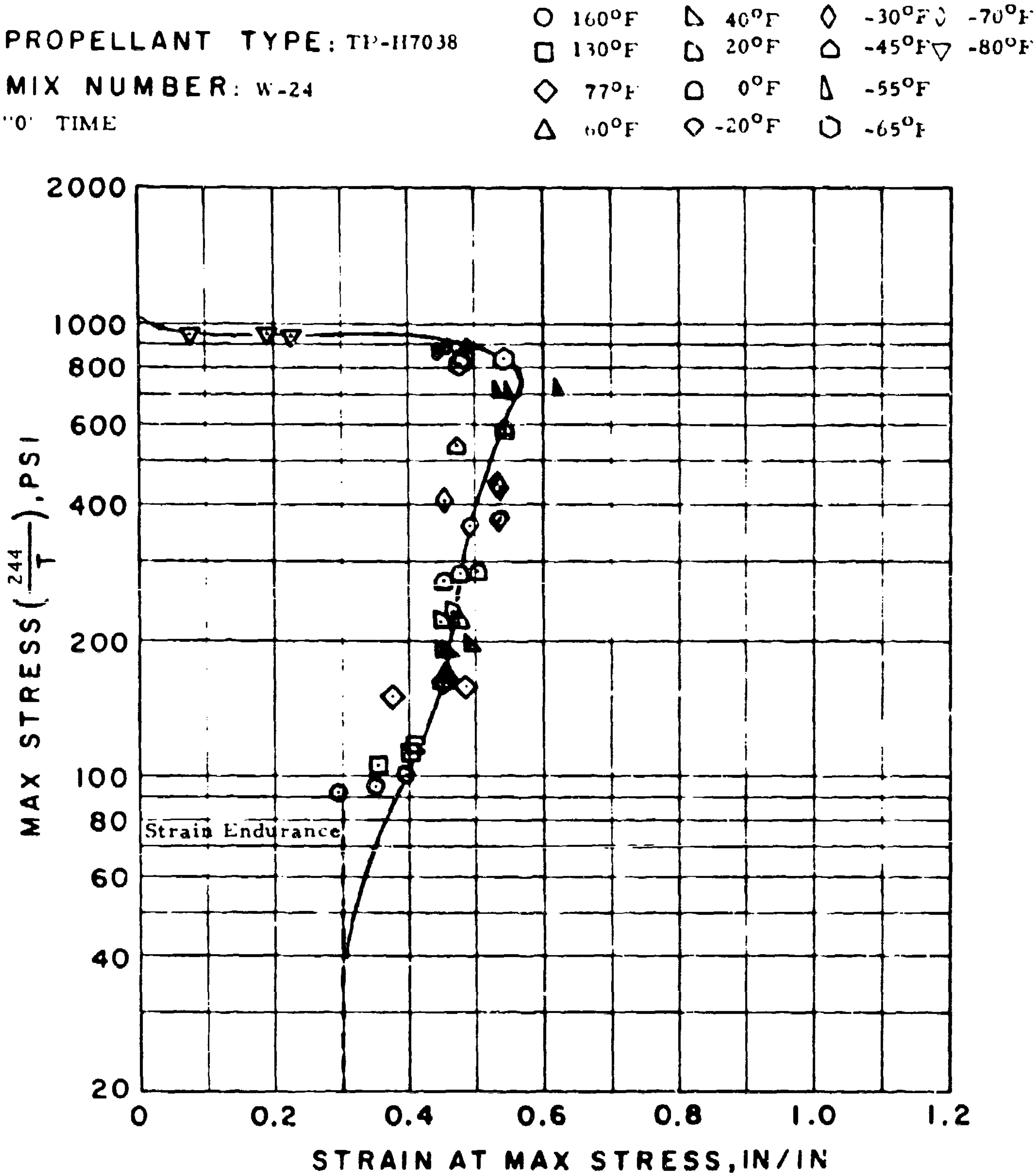


Figure 40. Failure Boundary, Modified TP-H7038 Propellant, Mix W-24

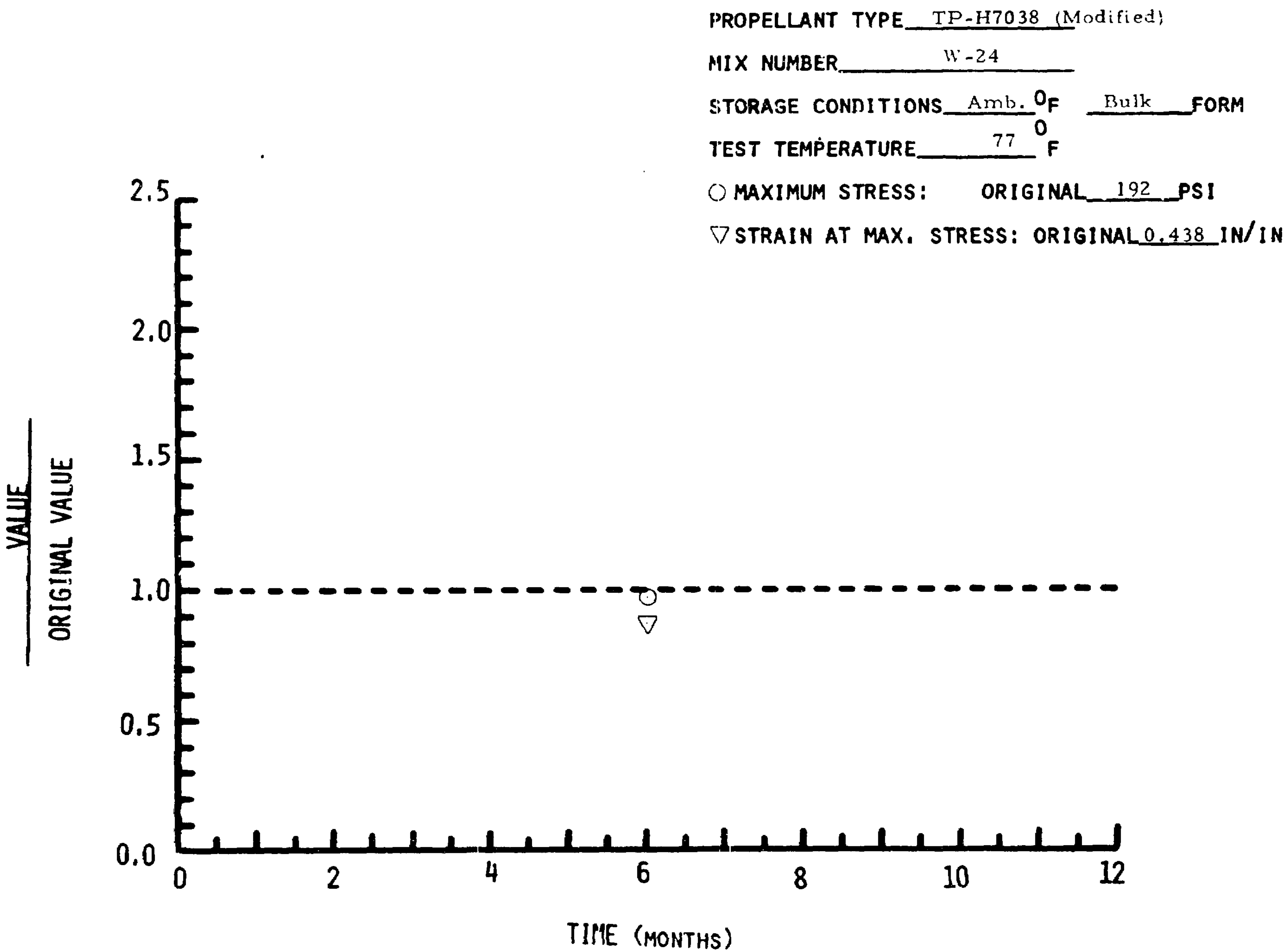


Figure 41. Effect of Ambient Storage on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Sealed Form

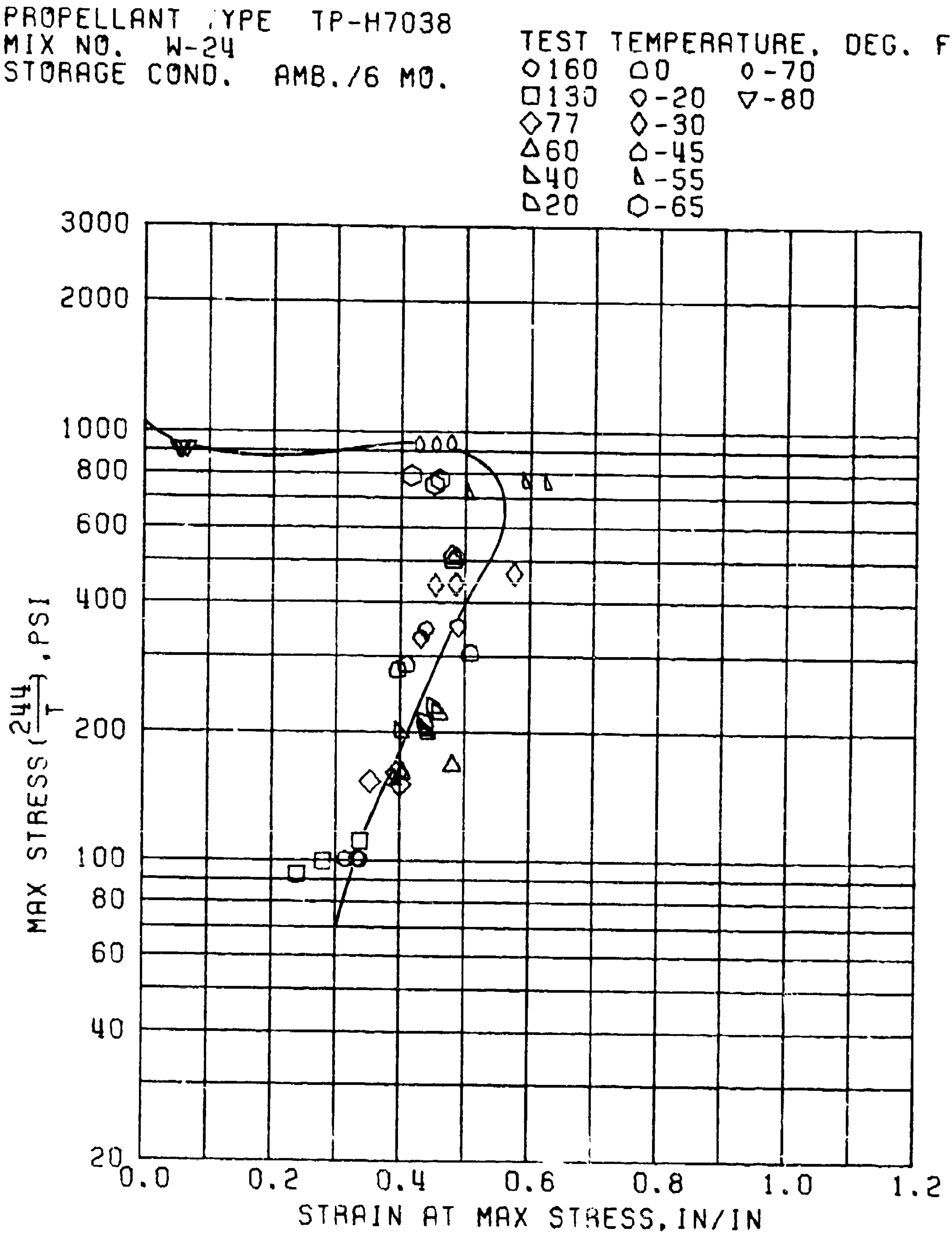


Figure 42. Failure Boundary, Modified TP-H7038 Propellant Stored Six Months at Ambient

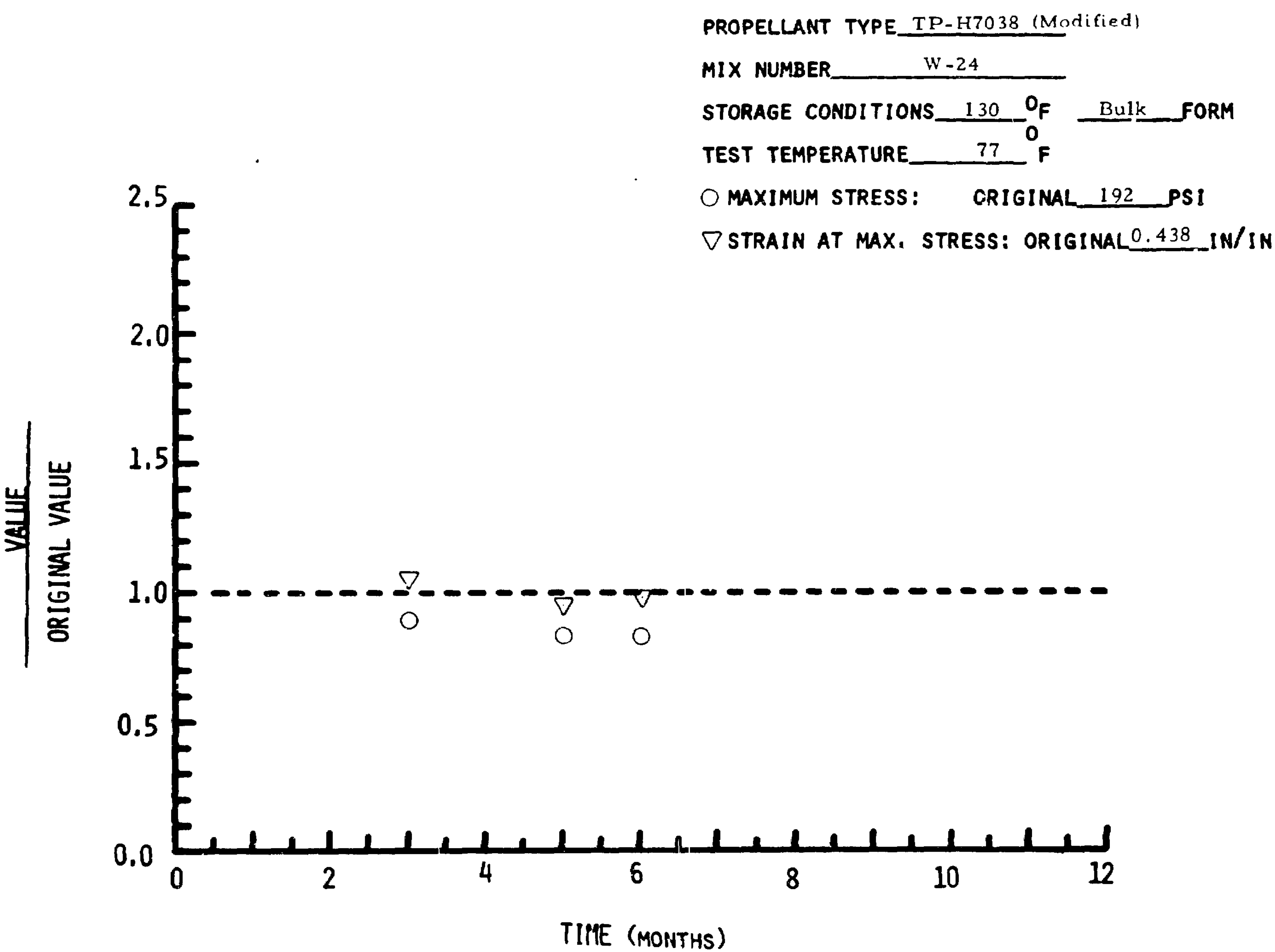


Figure 43. Effect of 130°F Storage on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Sealed Form

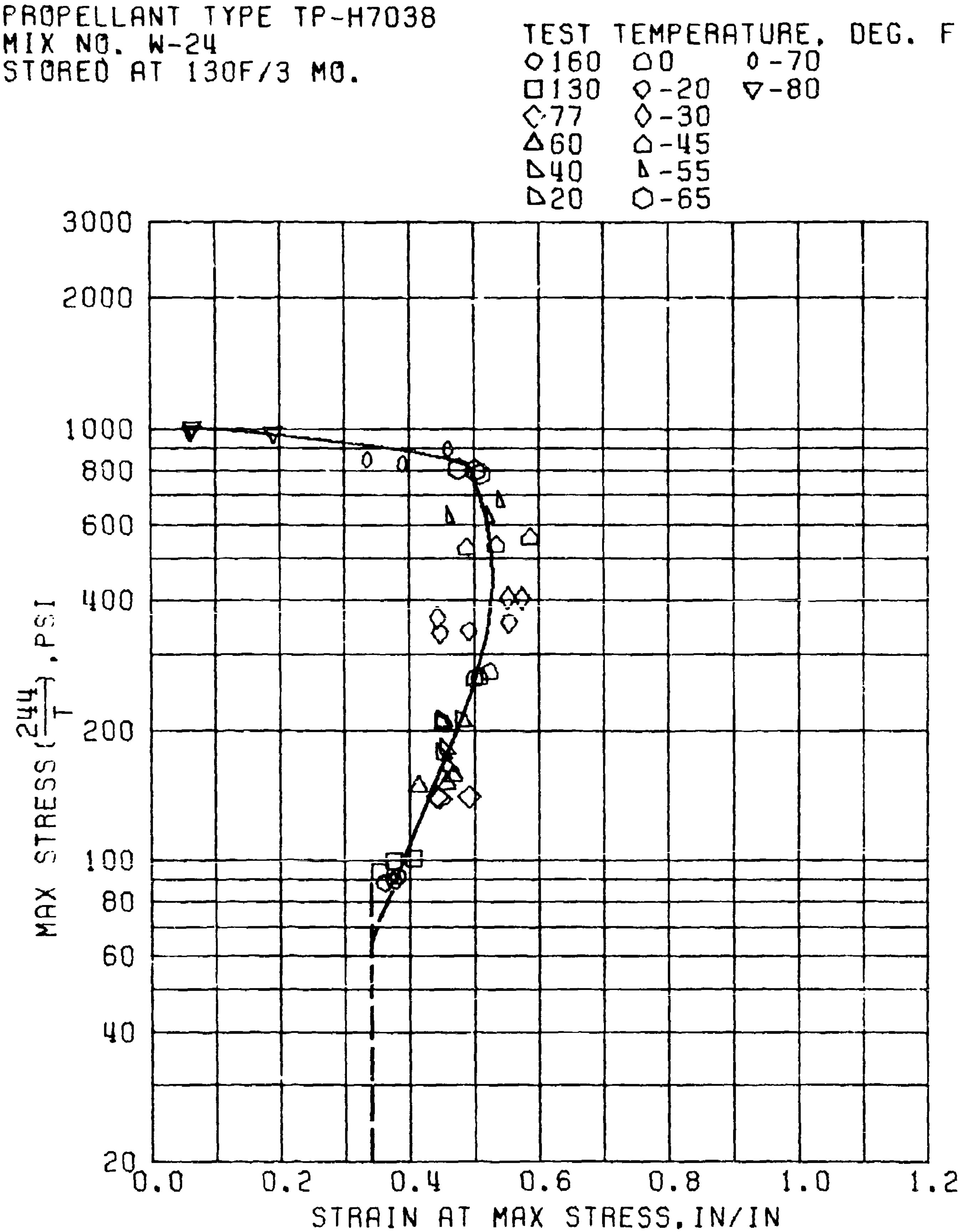


Figure 44. Failure Boundary, Modified TP-H7038 Propellant Stored Three Months at 130°F

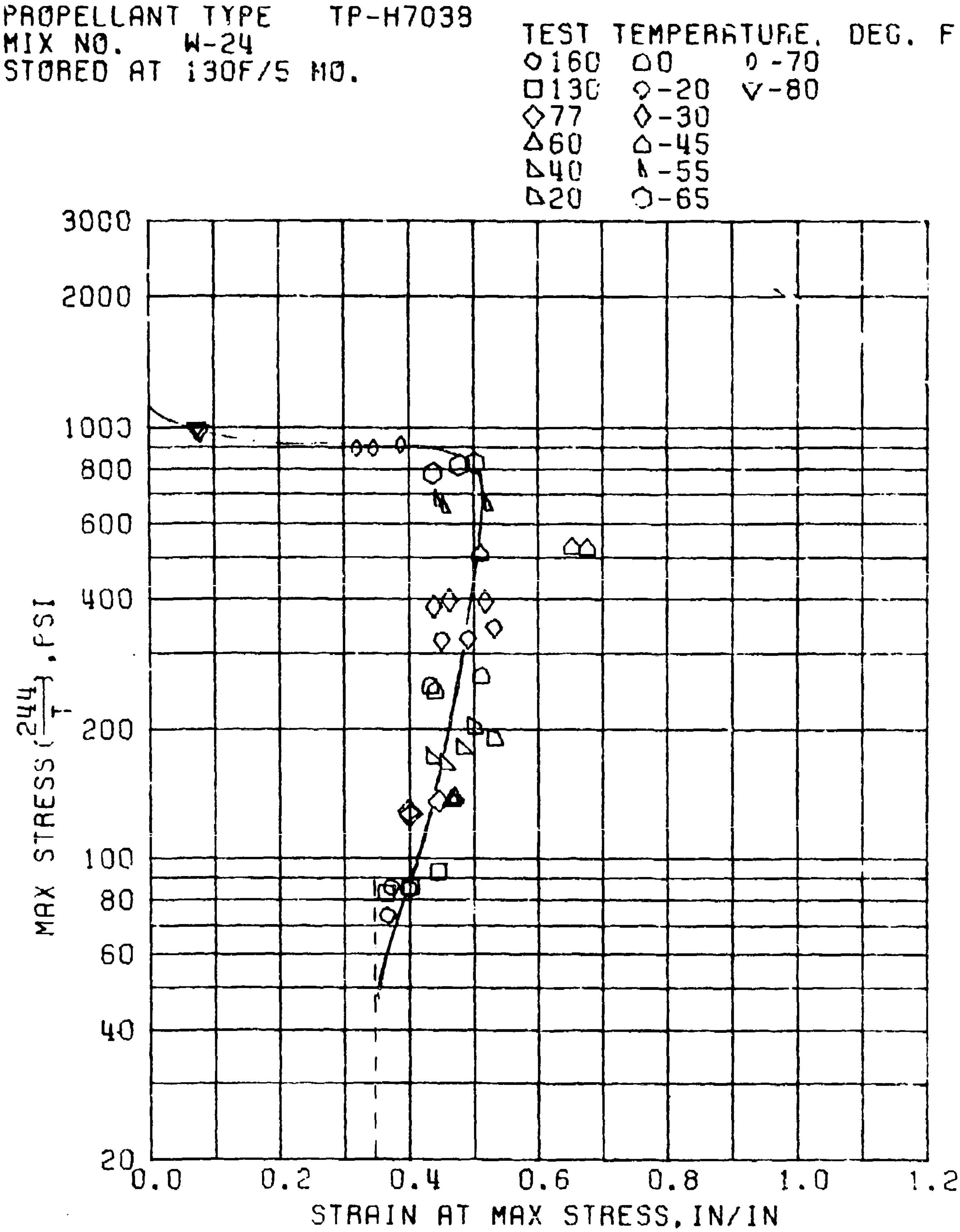


Figure 45. Failure Boundary, Modified TP-H7038 Propellant Stored Five Months at 130°F

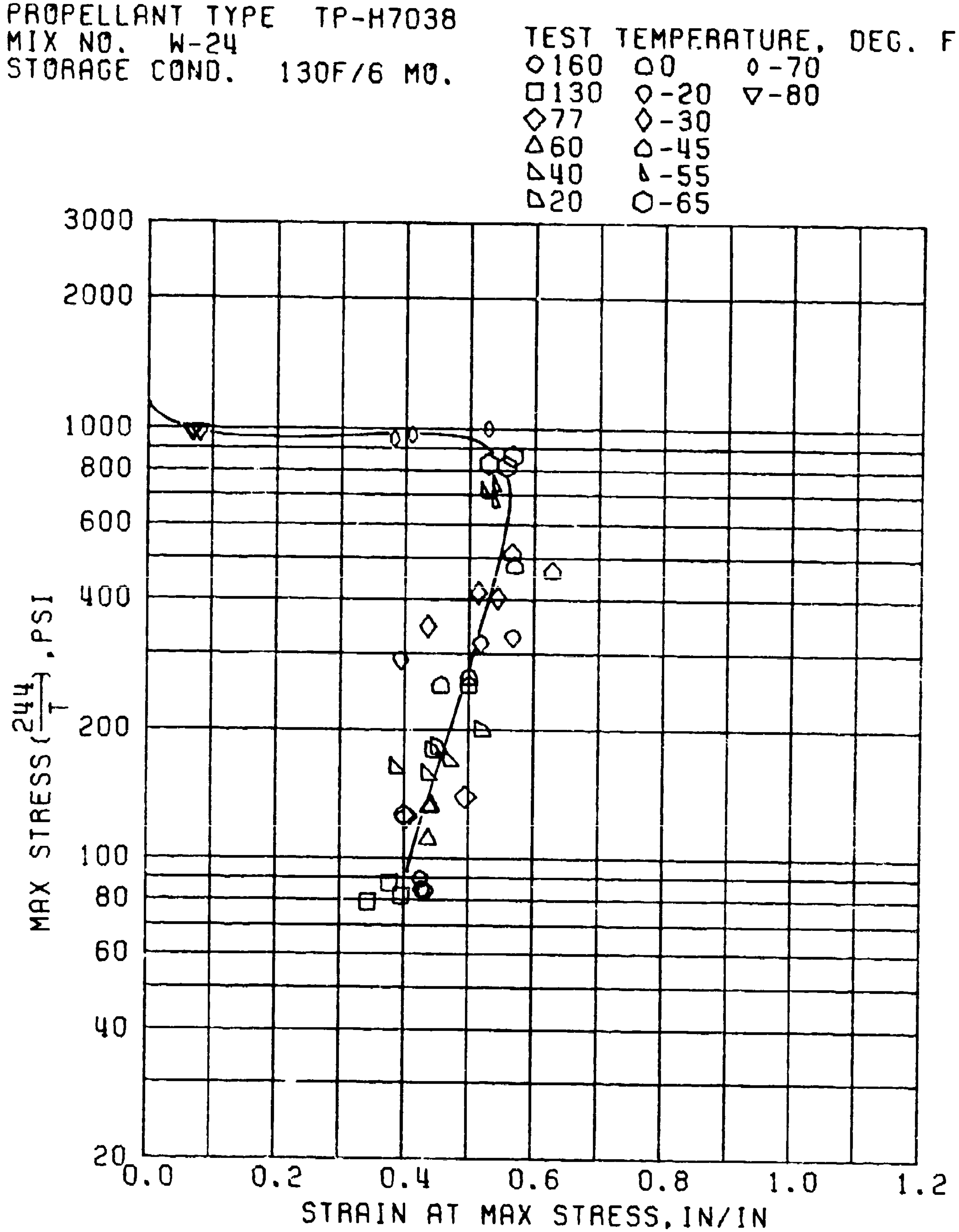


Figure 46. Failure Boundary, Modified TP-H7038 Propellant Stored Six Months at 130°F

Propellant Type TP-H7038 (Modified)
Mix Number W-24
Storage Conditions Amb. °F Gradient Form (N_2)
Test Temperature 77 °F
○ Maximum Stress; Original 185 psi
▽ Strain at Maximum Stress; Original 0.445 in/in
Storage Time 3 Months

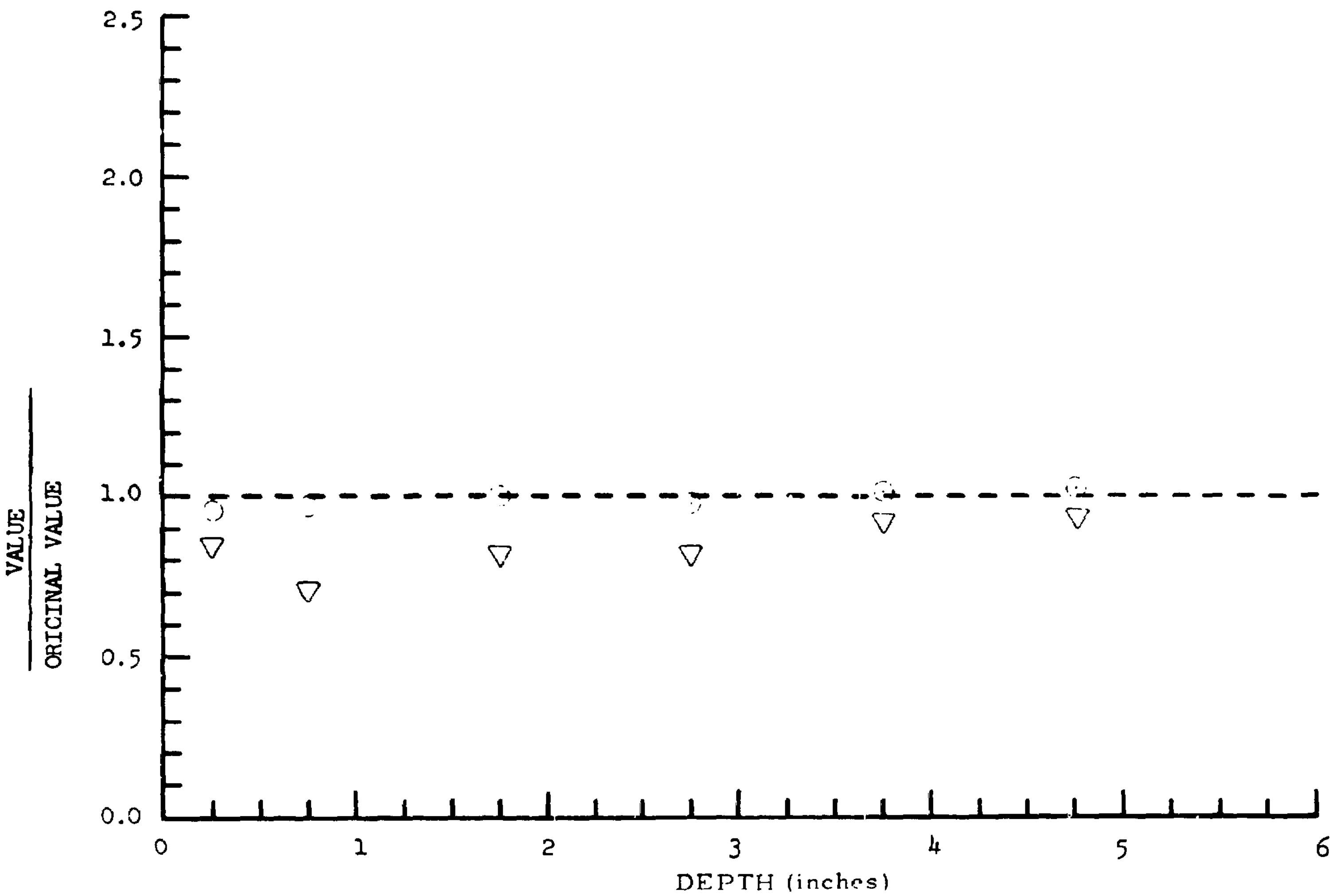


Figure 47. Effect of Ambient Storage for 3 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

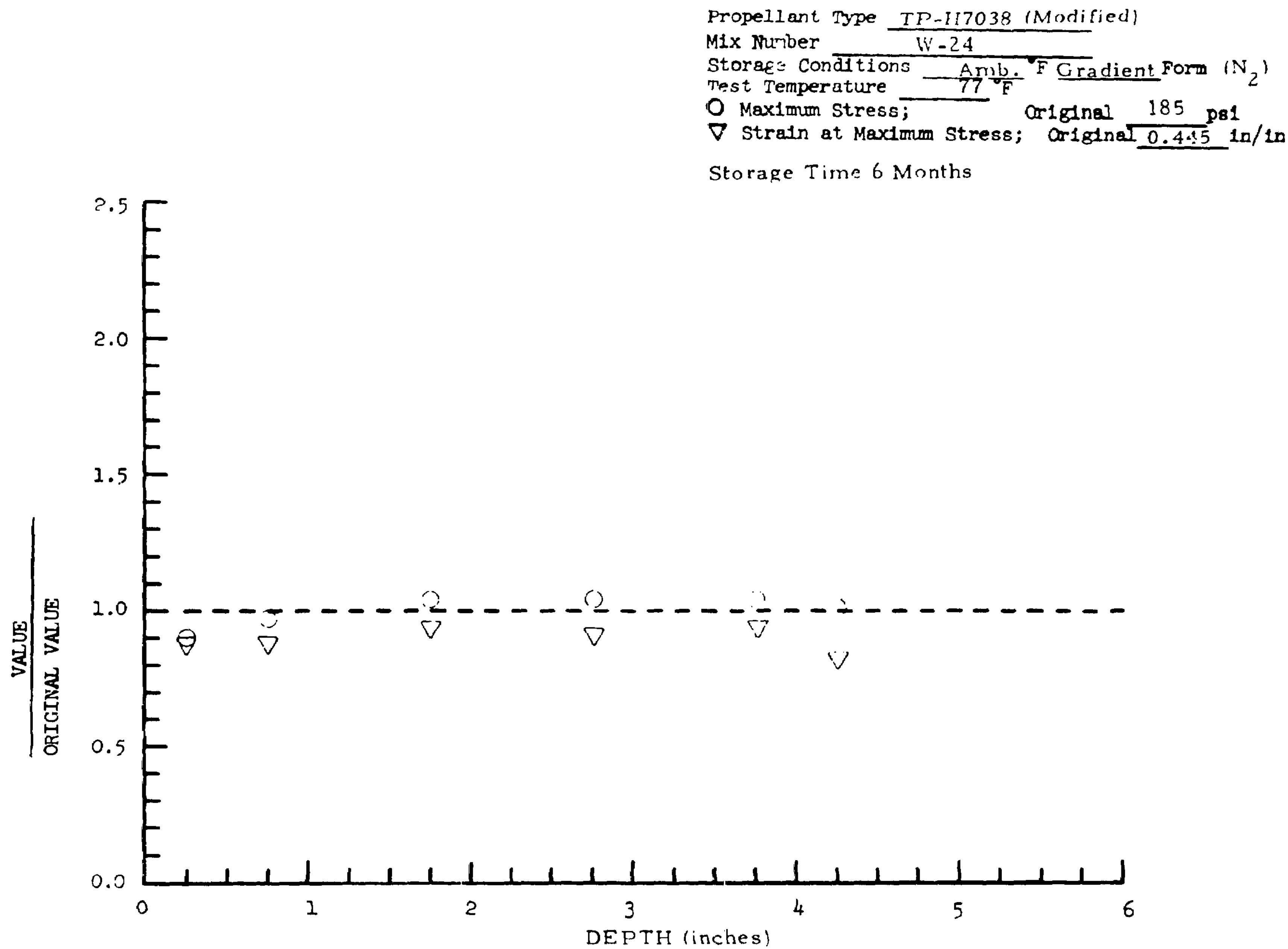


Figure 48. Effect of Ambient Storage for 6 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

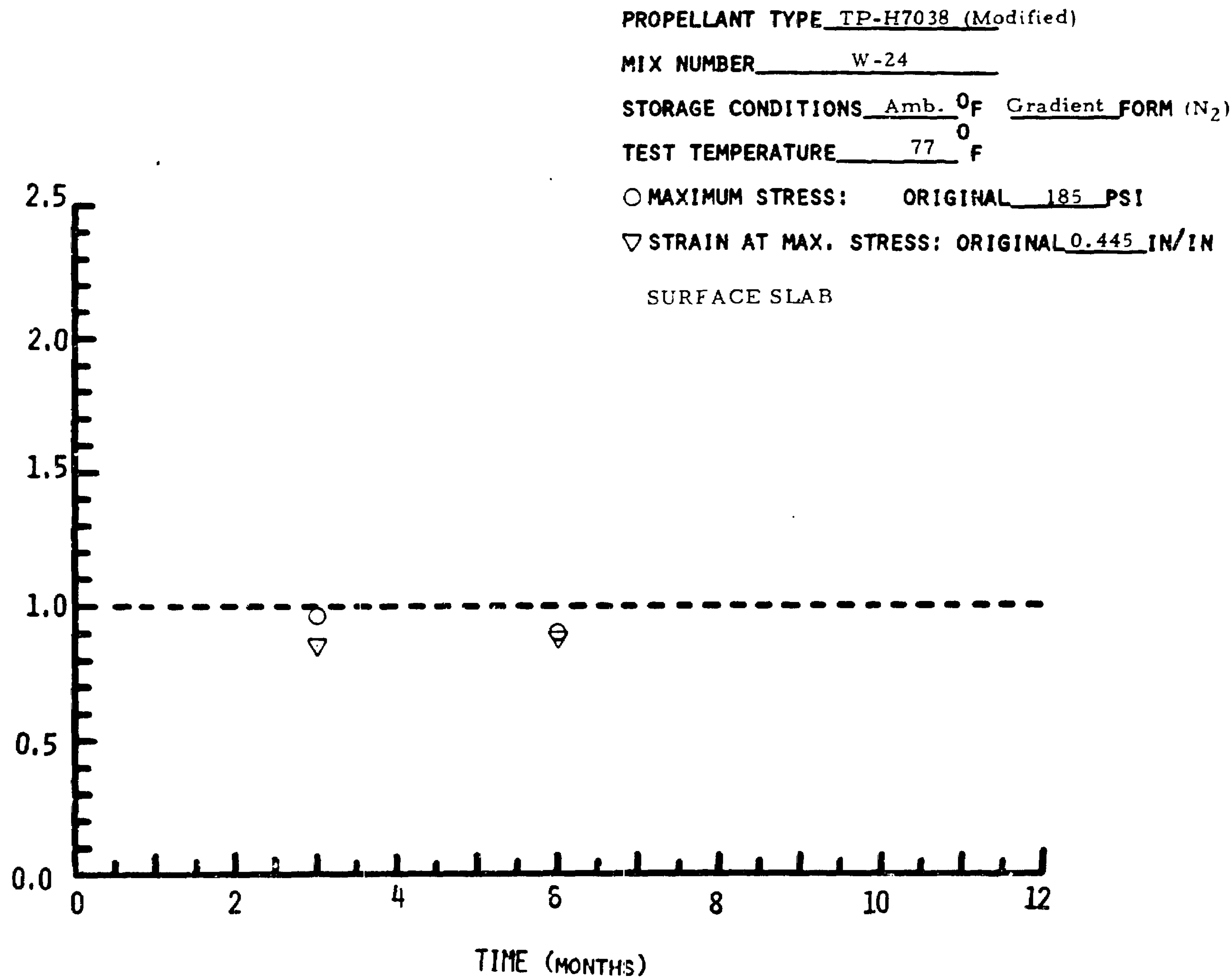


Figure 49. Effect of Ambient Storage on the Surface Slab Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

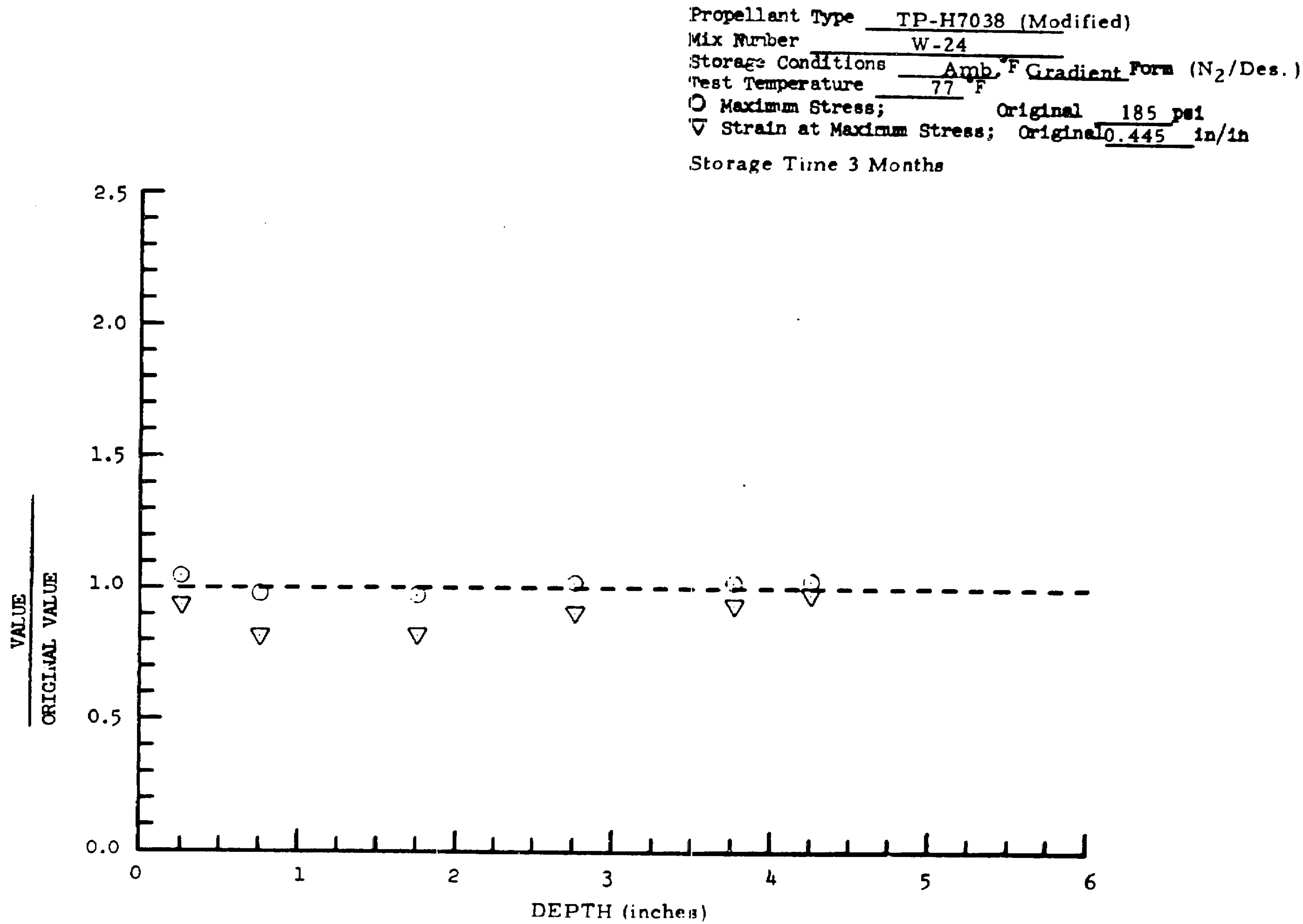


Figure 50. Effect of Ambient Storage for 3 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2, Des.)

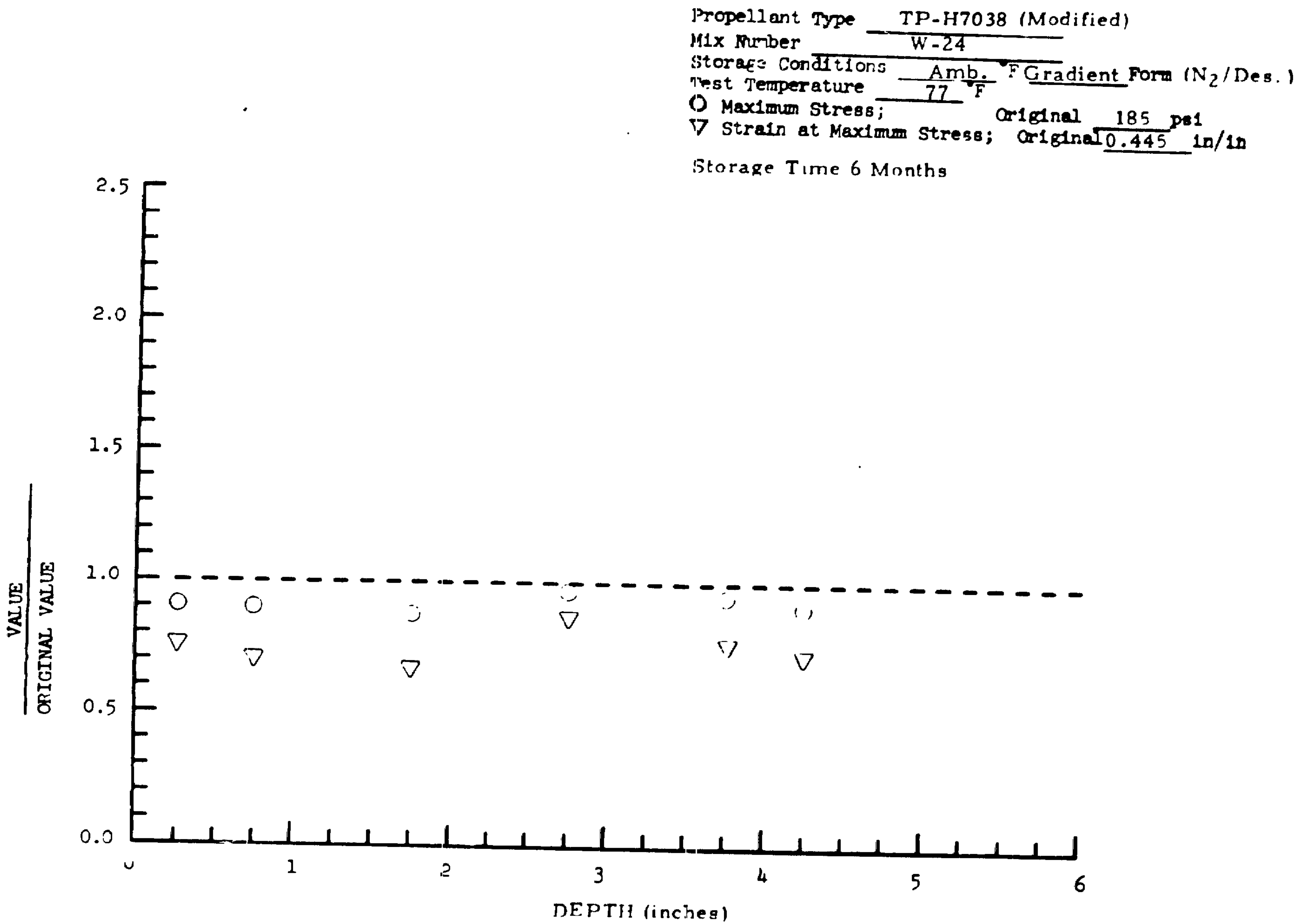


Figure 51. Effect of Ambient Storage for 6 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2, Des.)

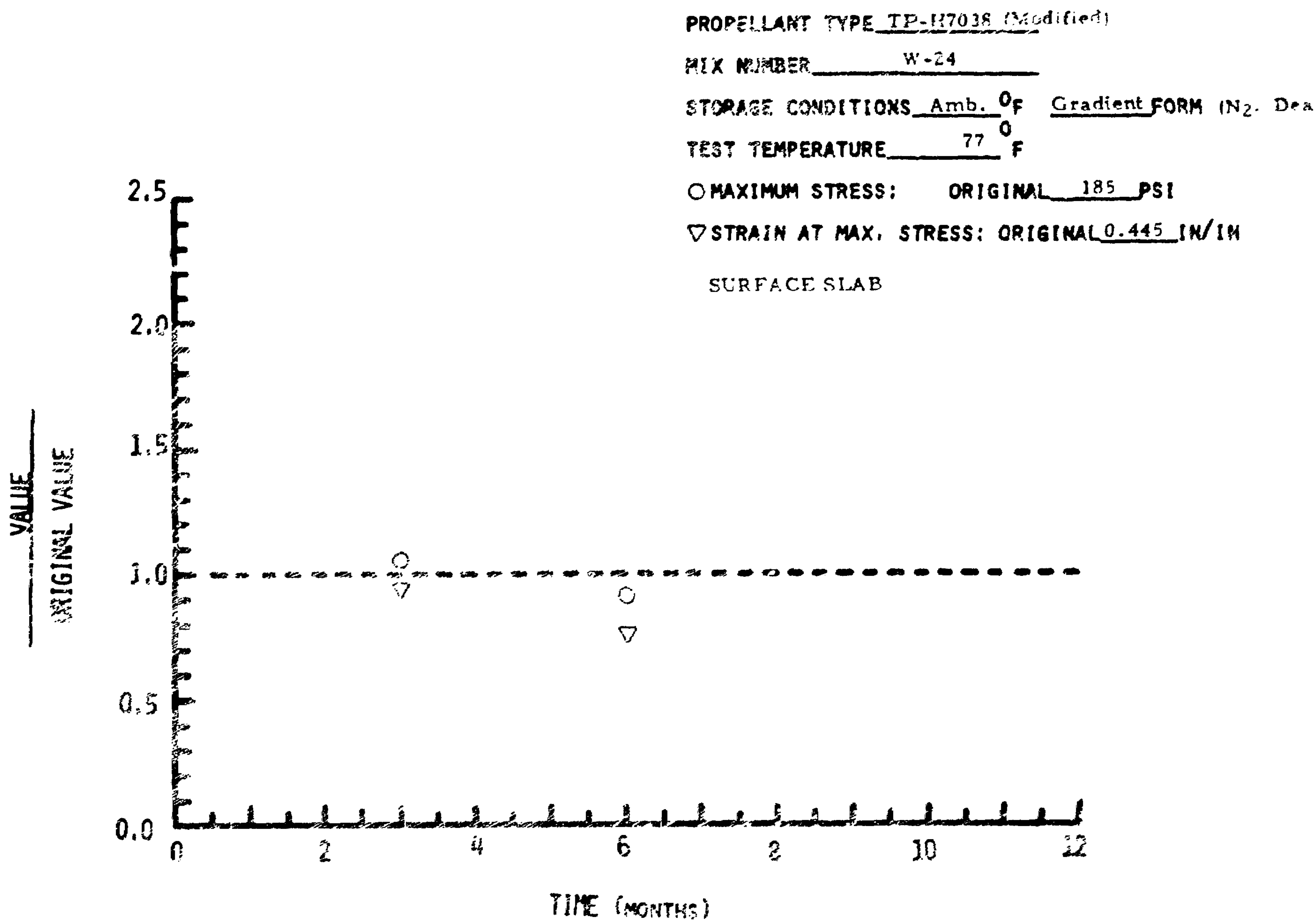


Figure 52. Effect of Ambient Storage on the Surface Slab Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2, Des.)

Propellant Type TP-H7038 (Modified)
Mix Number W-24
Storage Conditions 130 °F Gradient Form (N_2)
Test Temperature 77 °F
○ Maximum Stress; Original 185 psi
▽ Strain at Maximum Stress; Original 0.445 in/in

Storage Time 1 Month

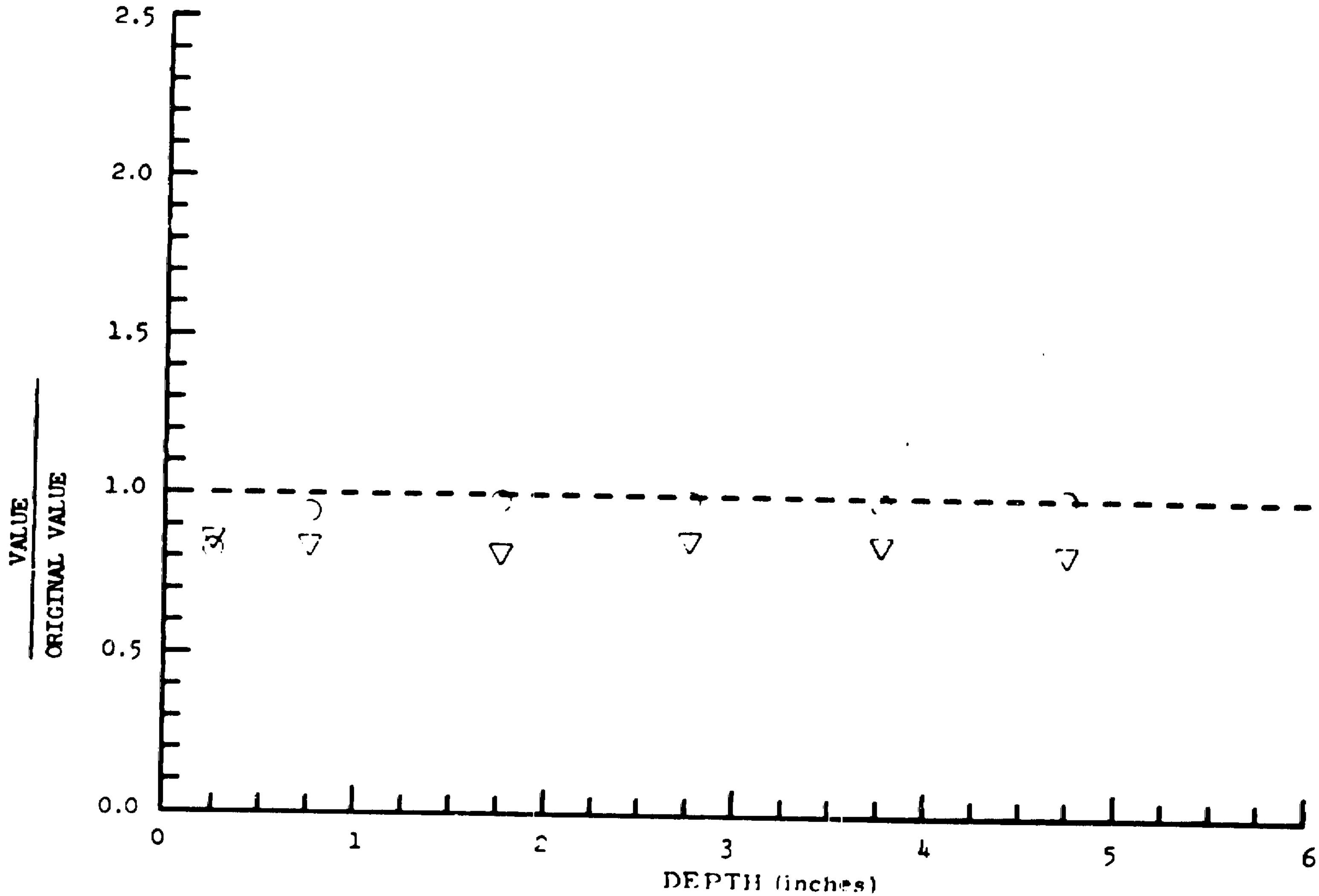


Figure 53. Effect of 130°F Storage for 1 Month on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

Propellant Type TP-H7038 (Modified)
Mix Number W-24
Storage Conditions 130 °F Gradient Form (N_2)
Test Temperature 77 °F
○ Maximum Stress; Original 185 psi
▽ Strain at Maximum Stress; Original 0.445 in/in

Storage Time 2 Months

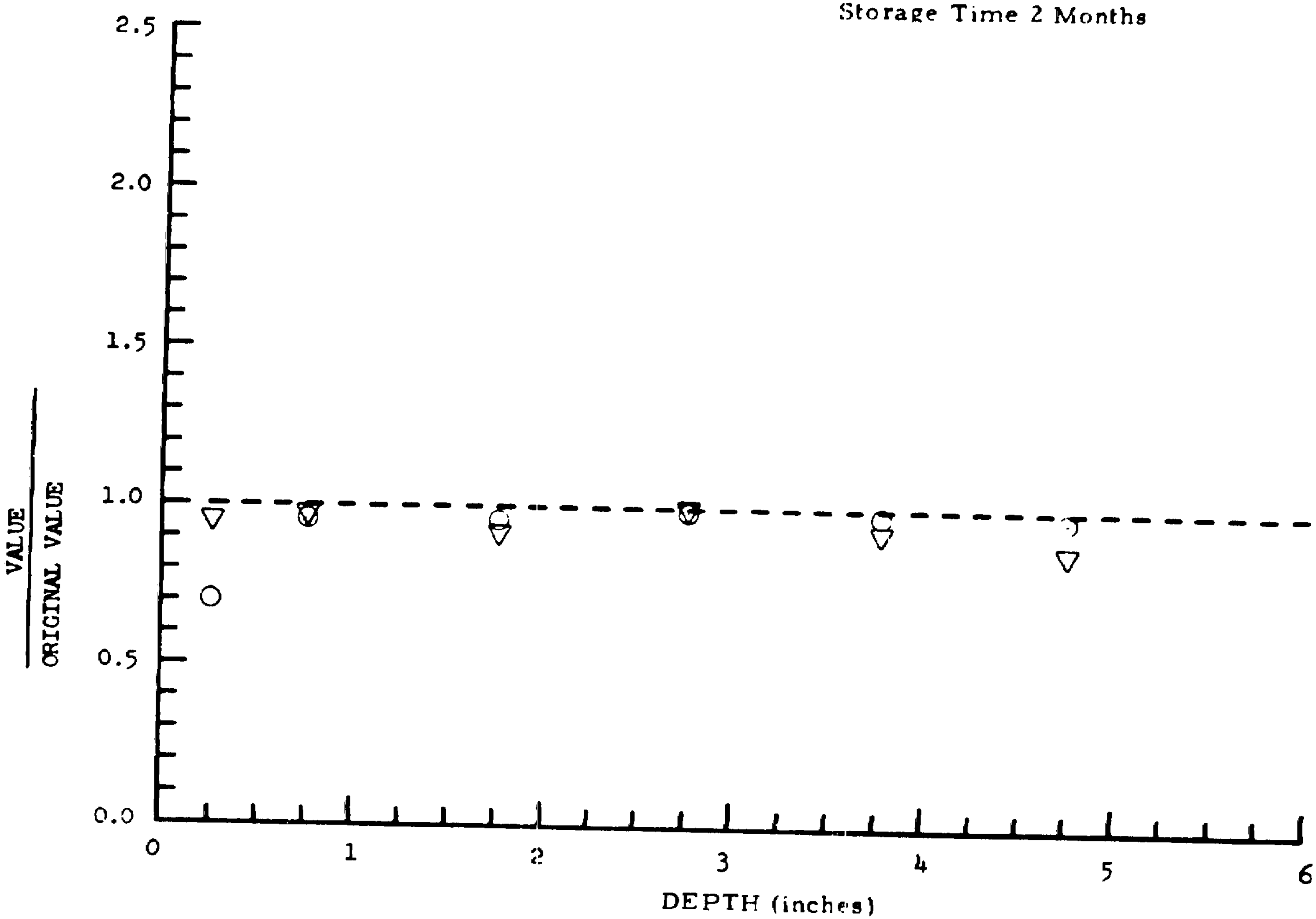


Figure 54. Effect of 130°F Storage for 2 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

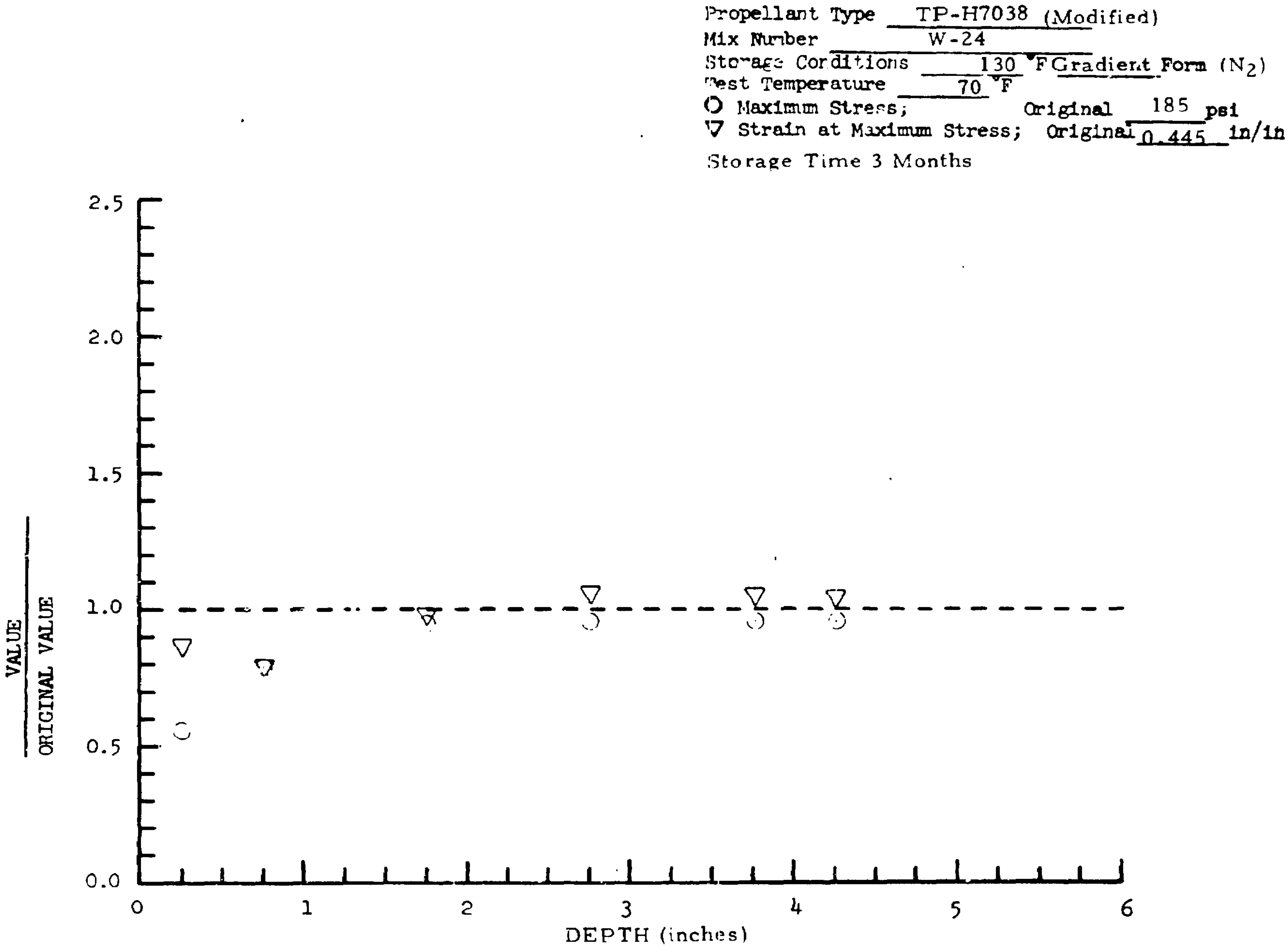


Figure 55. Effect of 130°F Storage for 3 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

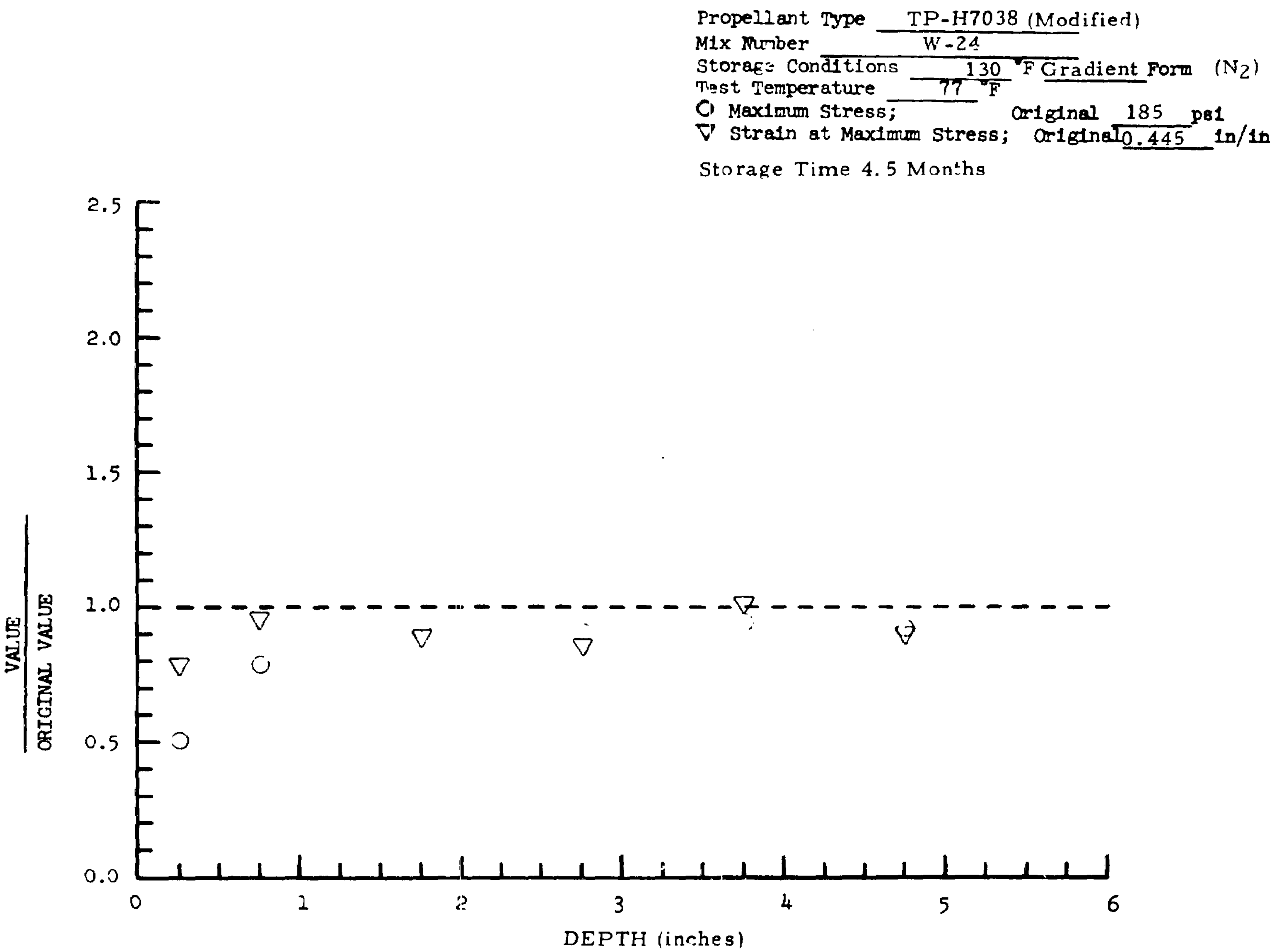


Figure 56. Effect of 130°F Storage for 4.5 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

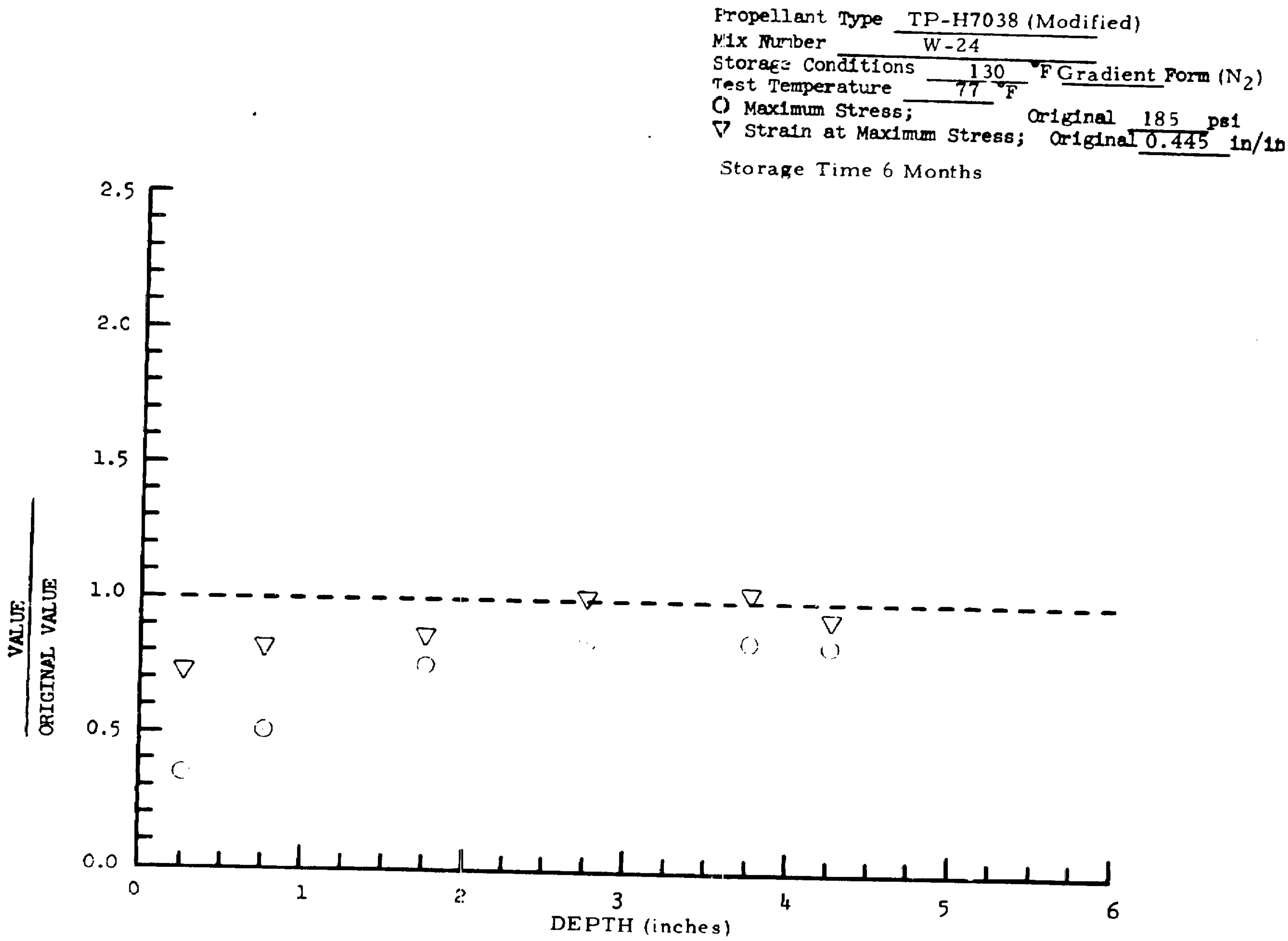


Figure 57. Effect of 130°F Storage for 6 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

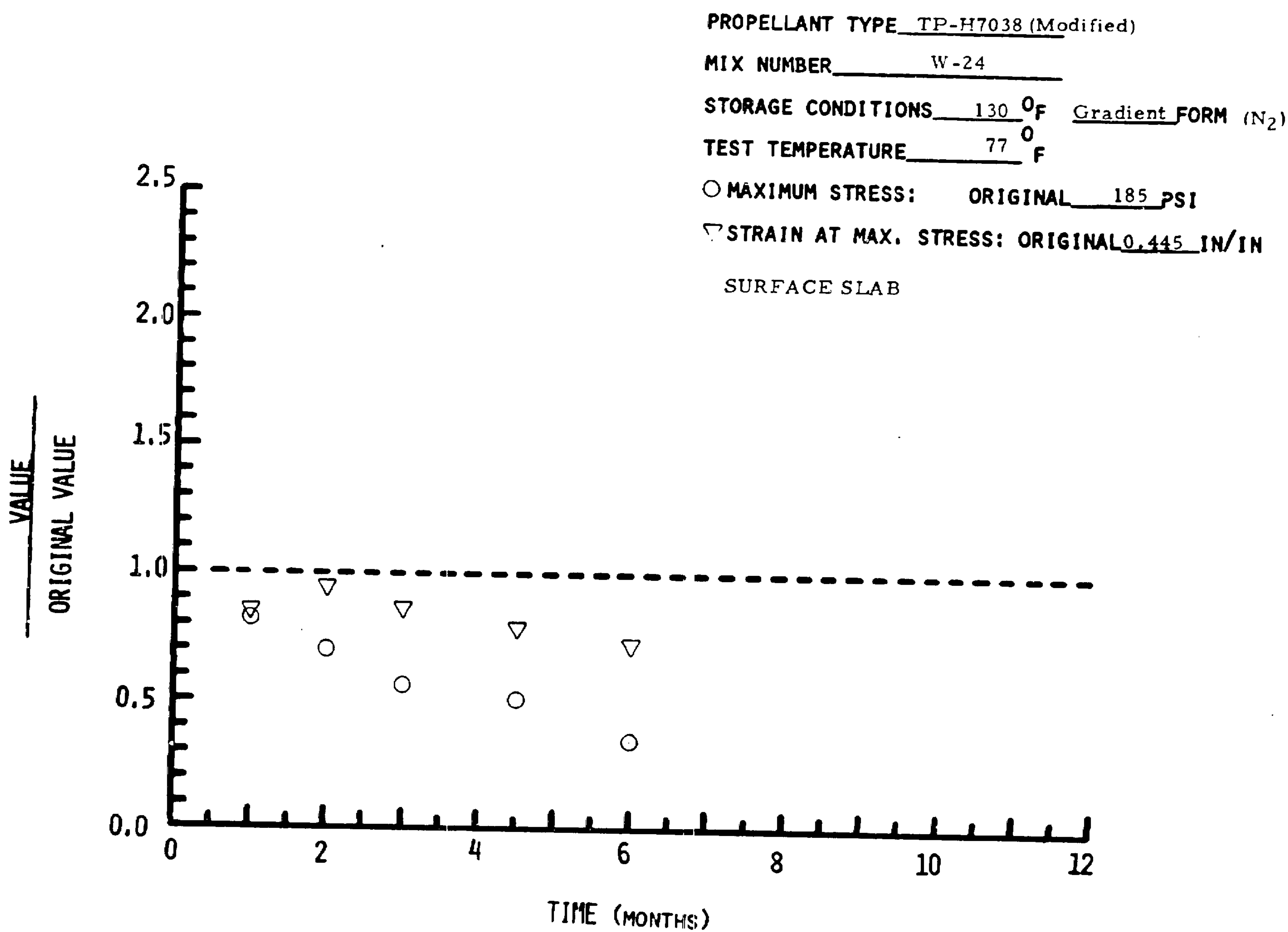


Figure 58. Effect of 130°F Storage on the Surface Slab Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2)

Propellant Type TP-H7038 (Modified)
Mix Number W-24
Storage Conditions 130 °F Gradient Form (N_2/Des.)
Test Temperature 77 °F
○ Maximum Stress; Original 185 psi
▽ Strain at Maximum Stress; Original 0.445 in/in

Storage Time 3 Months

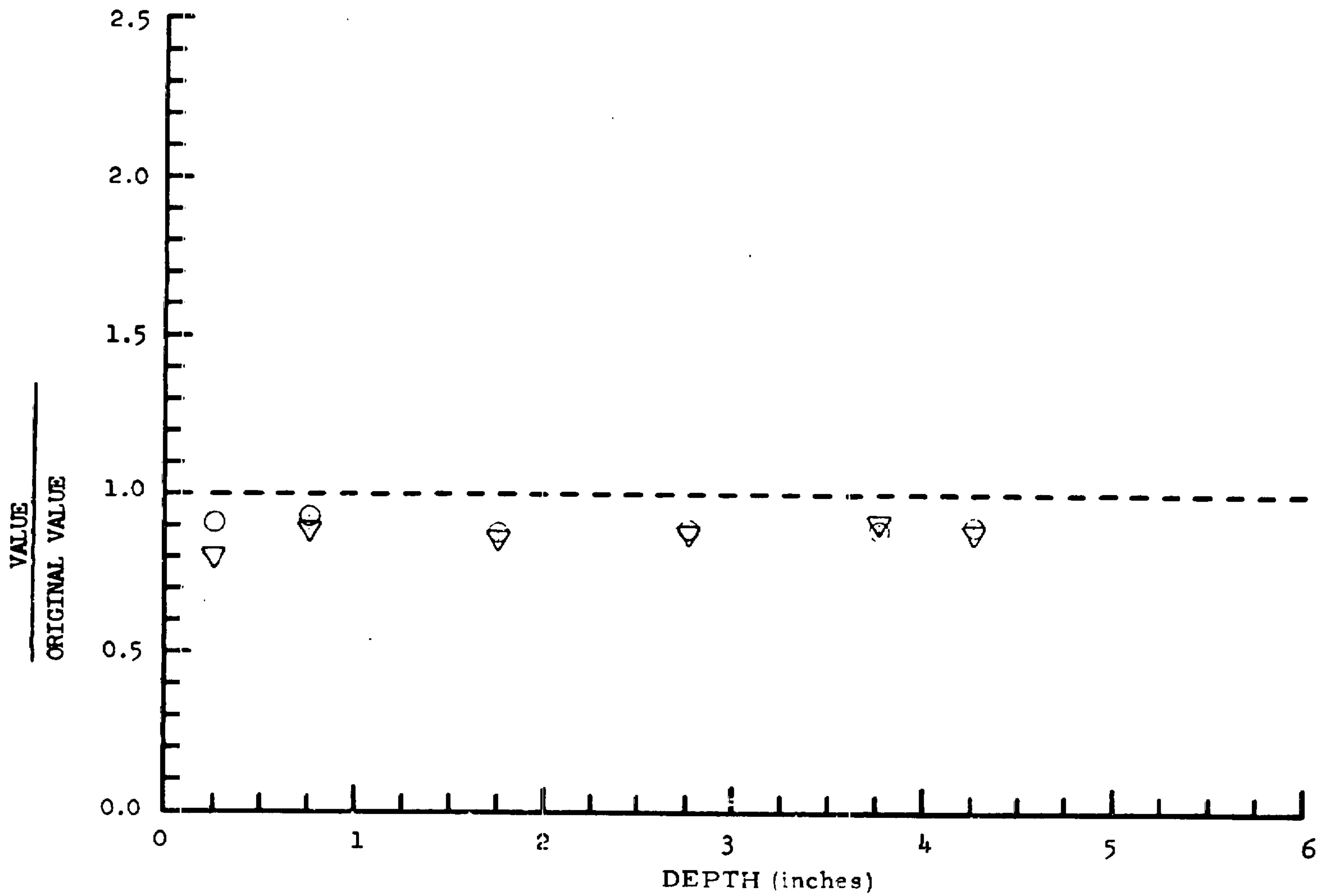


Figure 59. Effect of 130°F Storage for 3 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2, Des.)

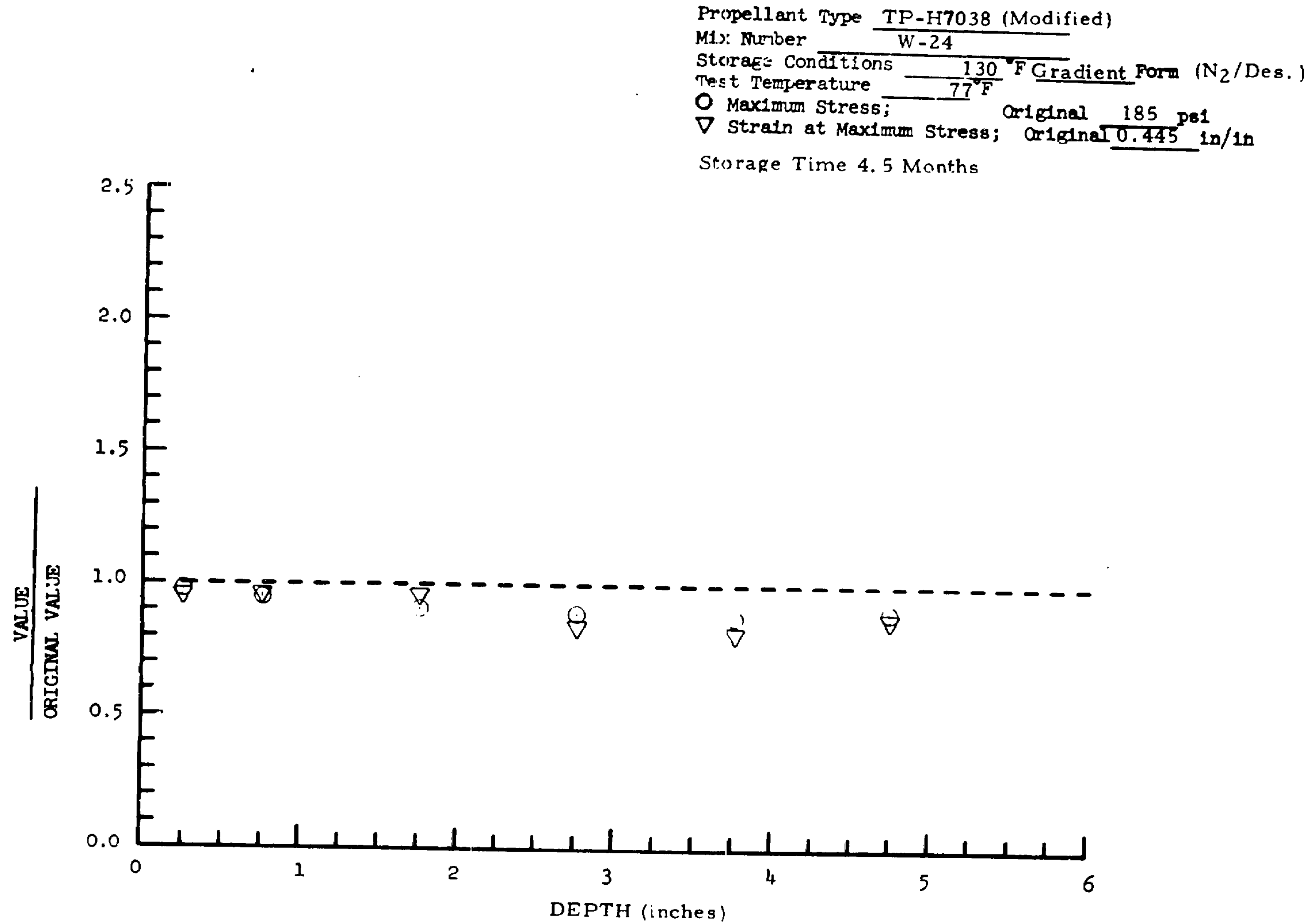


Figure 60. Effect of 130°F Storage for 4.5 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2, Des.)

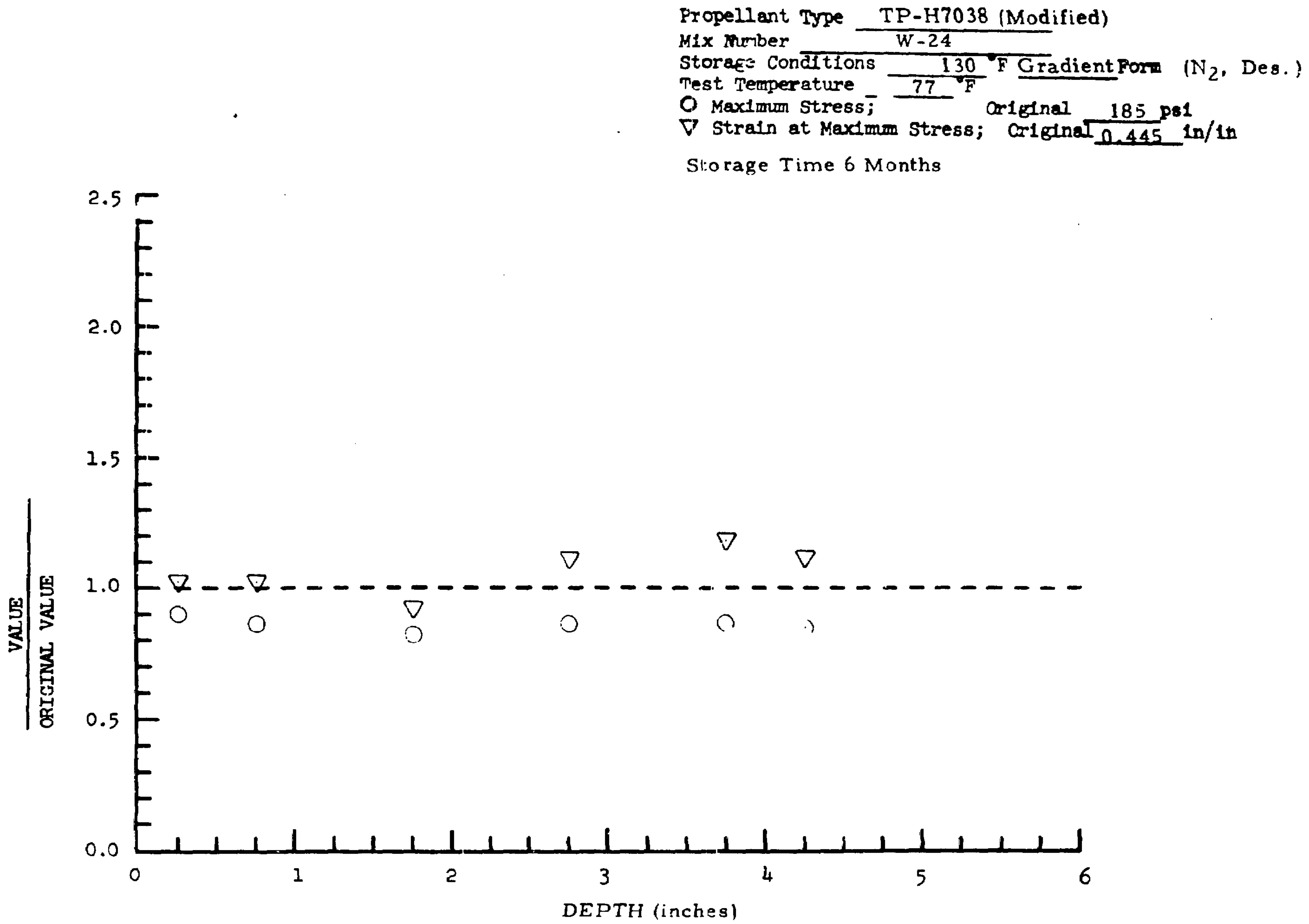


Figure 61. Effect of 130°F Storage for 6 Months on the Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2, Des.)

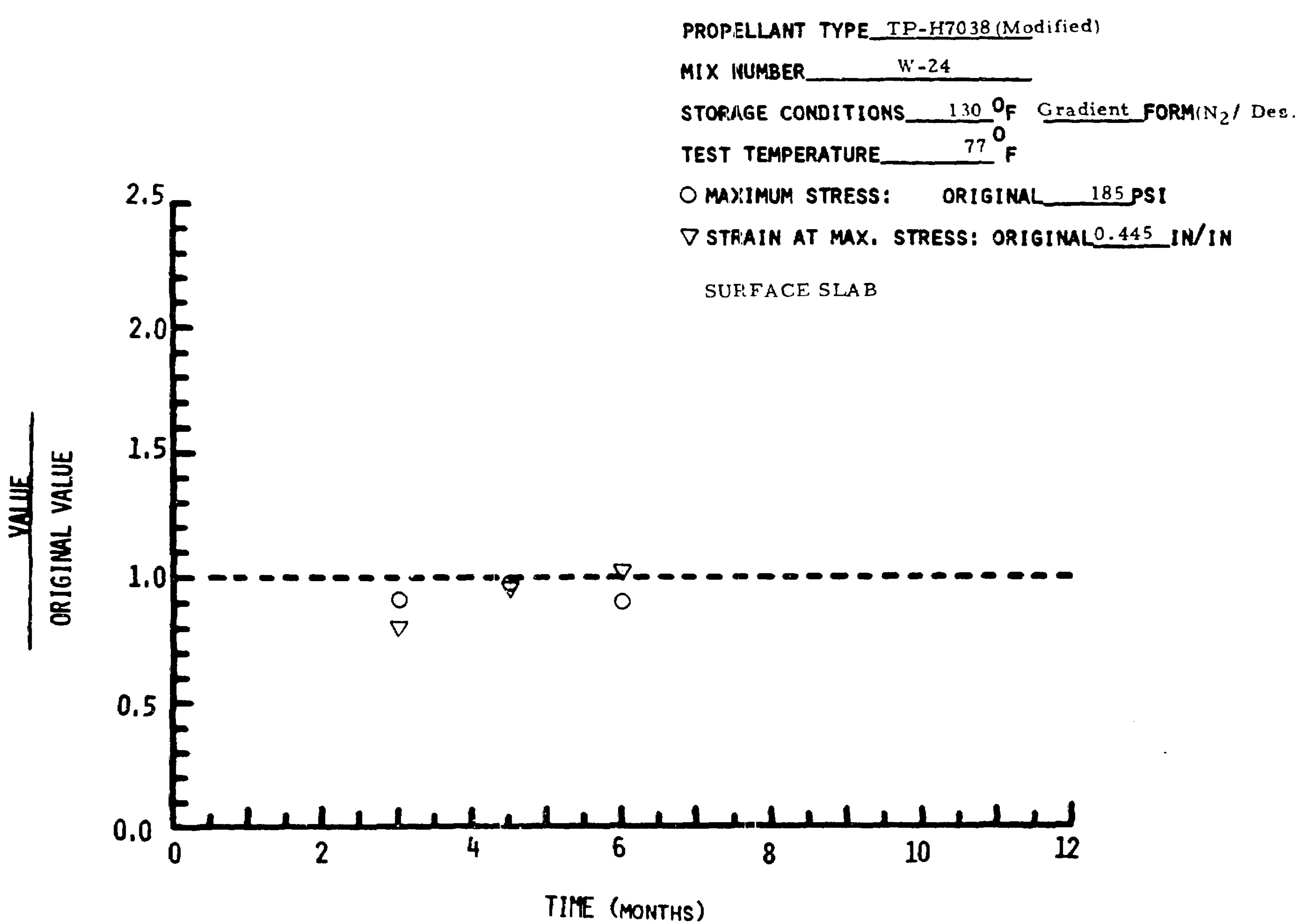


Figure 62. Effect of 130°F Storage on the Surface Slab Physical Properties of Modified TP-H7038 Propellant Stored in Bulk Gradient Form (N_2, Des.)

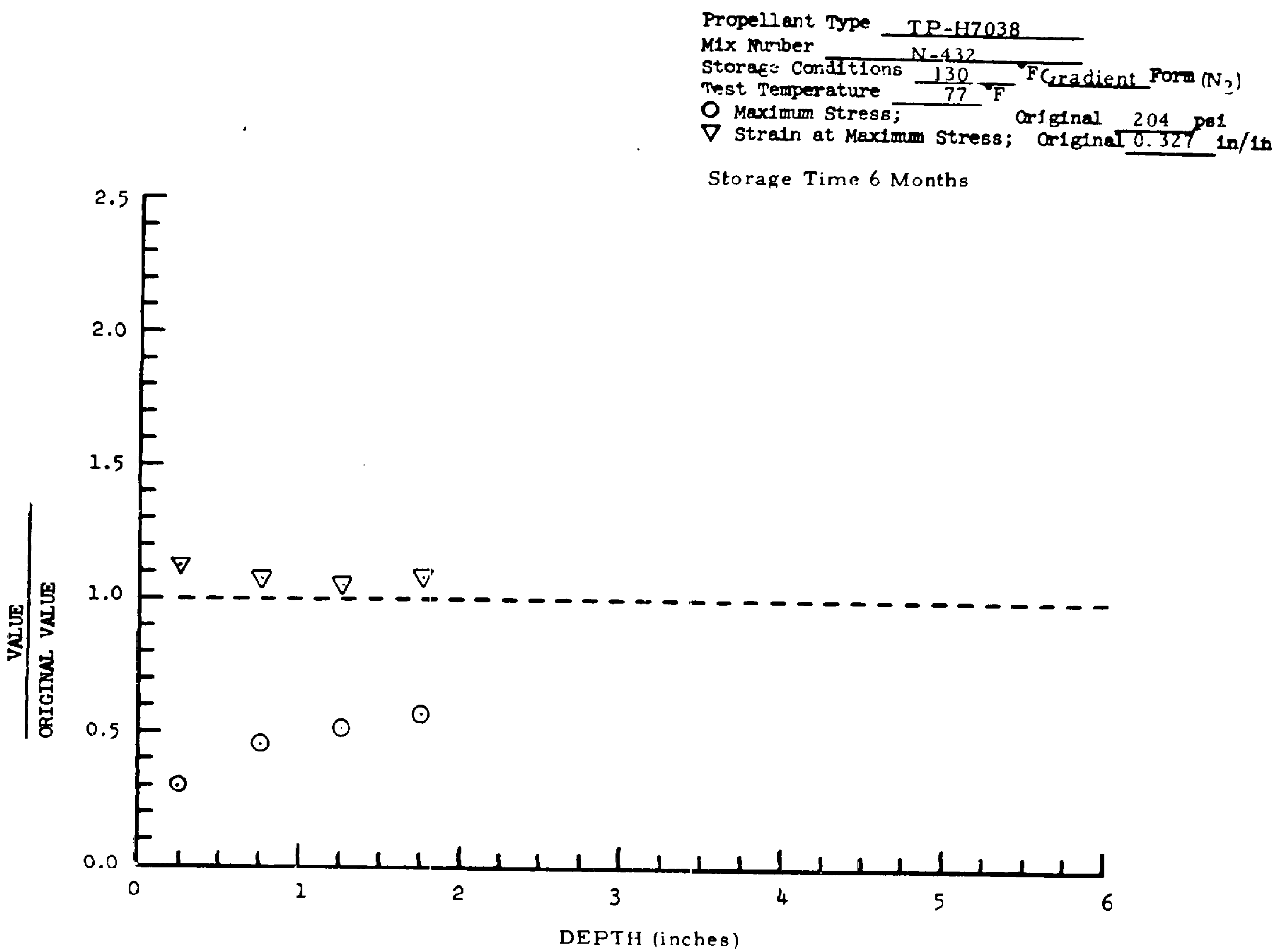


Figure 63. Effect of 130°F Storage for 6 Months on the Physical Properties of TP-H7038 Propellant (Mix N-432) Stored in Bulk Gradient Form (N_2)

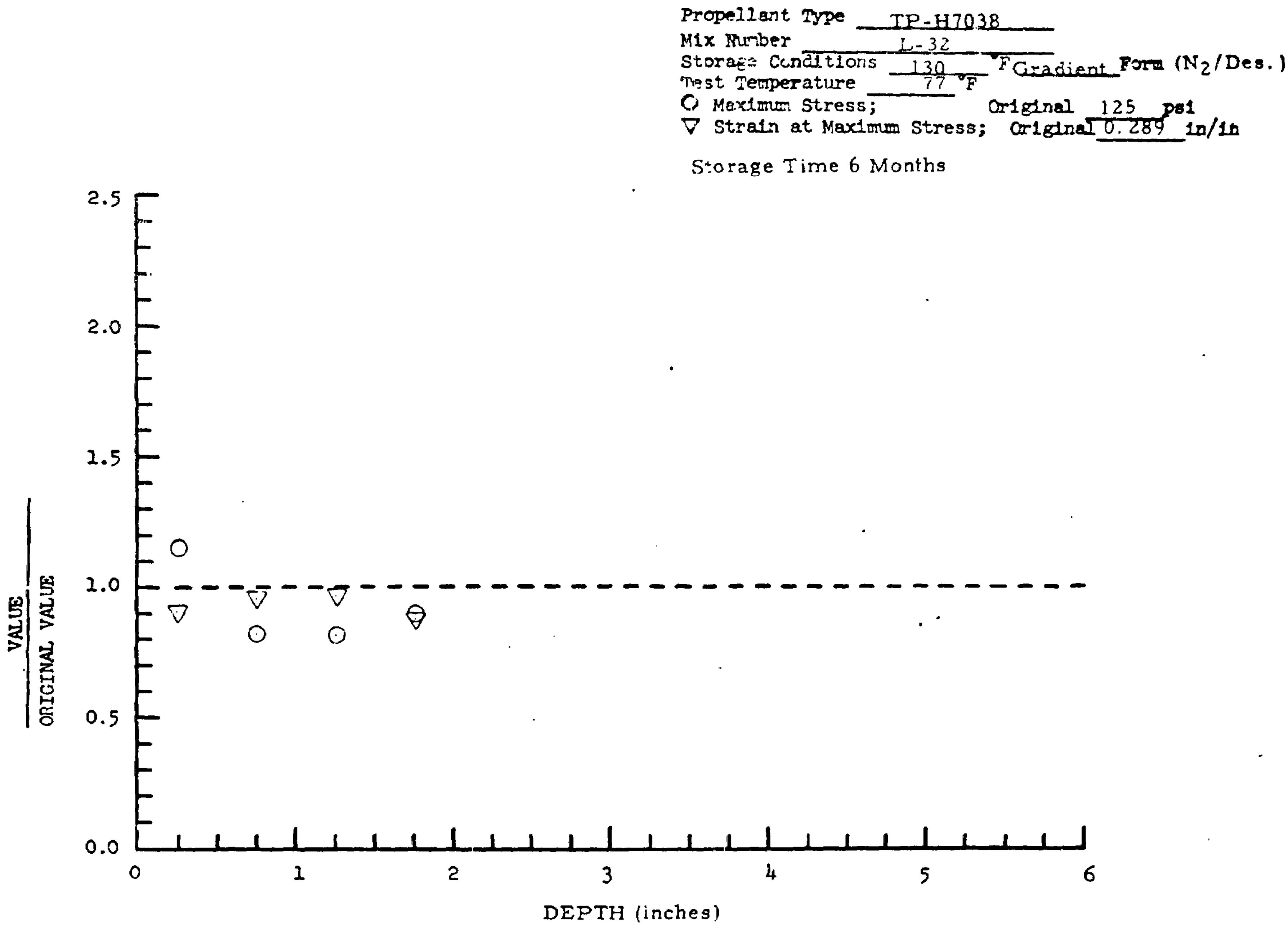


Figure 64. Effect of 130°F Storage for 6 Months on the Physical Properties of TP-H7038 Propellant (Mix L-32) Stored in Bulk Gradient Form (N_2, Des.)

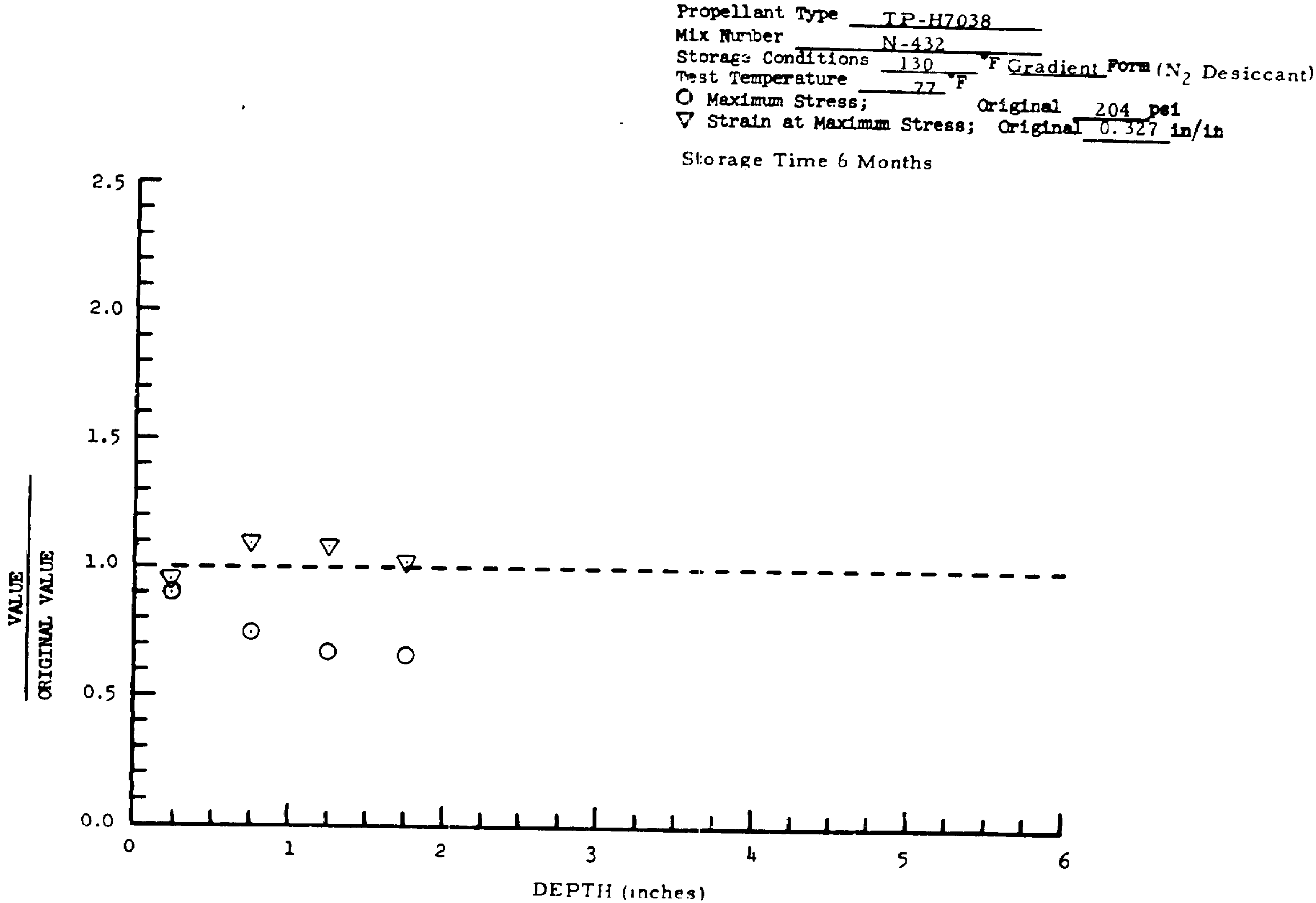


Figure 65. Effect of 130°F Storage for 6 Months on the Physical Properties of TP-H7038 Propellant (Mix N-432) Stored in Bulk Gradient Form (N_2, Des.)